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

Transmission media and optical systems characteristics –
Characteristics of optical components and subsystems

Application-related aspects of optical amplifier
devices and subsystems

Amendment 1

Recommendation ITU-T G.663 (2011) – Amendment 1



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Recommendation ITU-T G.663

Application-related aspects of optical amplifier devices and subsystems

Amendment 1

Summary

Recommendation ITU-T G.663 covers application-related aspects of optical amplifier (OA) devices and subsystems, primarily those used in digital systems. Applications include both single-channel and multi-channel systems used in point-to-point and point-to-multipoint configurations for use in long-distance networks and optical access networks. The purpose of this Recommendation is to identify which aspects should be considered for each application and to specify appropriate parameter values and ranges for each type of OA device. In this version of this Recommendation, information about non-linear optical effects in Appendix II is updated.

Amendment 1 adds a new clause II.3.4 to Appendix II for cross-polarization modulation and updates the list of abbreviations in clause 4.

History

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FOREWORD

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

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

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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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Recommendation ITU-T G.663

Application-related aspects of optical amplifier devices and subsystems

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T G.663 (2011).

1 Scope

This Recommendation covers application-related aspects of optical amplifier (OA) devices and subsystems, primarily those used in digital systems. Optical amplifiers operating in the 1550 nm region, or 1310 nm region, or other wavelength regions are included. Generic characteristics of OA devices and subsystems are described in [ITU-T G.662]. Applications include both single-channel and multi-channel systems used in point-to-point and point-to-multipoint configurations for use in long-distance networks and optical access networks.

The purpose of this Recommendation is to identify which aspects should be considered for each application and to specify common parameter values and ranges for each type of OA device (booster amplifier, pre-amplifier, and line amplifier). This Recommendation pertains to the development of new equipment including OA devices and includes guidelines to apply OA devices and OA subsystems to existing equipment. As an objective, for systems specified as transversely compatible, the degree of compatibility should not be changed by the use of OA devices.

Important topics contained in this Recommendation include transmission aspects, maintenance aspects, and optical safety.

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.652] Recommendation ITU-T G.652 (2009), *Characteristics of a single-mode optical fibre and cable*.
- [ITU-T G.653] Recommendation ITU-T G.653 (2010), *Characteristics of a dispersion-shifted, single-mode optical fibre and cable*.
- [ITU-T G.654] Recommendation ITU-T G.654 (2010), *Characteristics of a cut-off shifted, single-mode optical fibre and cable*.
- [ITU-T G.655] Recommendation ITU-T G.655 (2009), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.
- [ITU-T G.661] Recommendation ITU-T G.661 (2007), *Definition and test methods for the relevant generic parameters of optical amplifier devices and subsystems*.
- [ITU-T G.662] Recommendation ITU-T G.662 (2005), *Generic characteristics of optical amplifier devices and subsystems*.
- [ITU-T G.664] Recommendation ITU-T G.664 (2006), *Optical safety procedures and requirements for optical transport systems*.

- [ITU-T G.671] Recommendation ITU-T G.671 (2009), *Transmission characteristics of optical components and subsystems*.
- [ITU-T G.691] Recommendation ITU-T G.691 (2006), *Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers*.
- [ITU-T G.692] Recommendation ITU-T G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.
- [ITU-T G.783] Recommendation ITU-T G.783 (2006), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.
- [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*.
- [IEC 60721-3-0] IEC 60721-3-0 (1997), *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities. Introduction*.
- [IEC 60721-3-1] IEC 60721-3-1 (1997), *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 1: Storage*.
- [IEC 60721-3-2] IEC 60721-3-2 (1997), *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation*.
- [IEC 60721-3-3] IEC 60721-3-3 (1994), *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 3: Stationary use at weatherprotected locations*.
- [IEC 60721-3-4] IEC 60721-3-4 (1995), *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 4: Stationary use at non-weatherprotected locations*.
- [IEC 60825-1] IEC 60825-1 (2007), *Safety of laser products – Part 1: Equipment classification and requirements*.
- [IEC 60825-2] IEC 60825-2 (2010), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*.
- [IEC/TR 61282-3] IEC/TR 61282-3 (2006), *Fibre optic communication system design guides – Part 3: Calculation of link polarization mode dispersion*.

3 Definitions

For the purpose of this Recommendation, the definitions given in [ITU-T G.661] and [ITU-T G.662] apply.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AM	Amplitude Modulation
APR	Automatic Power Reduction
ASE	Amplified Spontaneous Emission

ASK	Amplitude Shift Keying
BA	Booster (power) Amplifier
BER	Bit Error Ratio
CD	Chromatic Dispersion
CMC	Coherent Multichannel
CW	Continuous Wave
DA	Dispersion Accommodation
<u>DP</u>	<u>Dual Polarization</u>
DPSK	Differential Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
EDFA	Erbium-Doped Fibre Amplifier
FDM	Frequency-Division Multiplexing
FWHM	Full Width at Half Maximum
FWM	Four-Wave Mixing
IFWM	Intra-channel Four-Wave Mixing
IXPM	Intra-channel Cross-Phase Modulation
LA	Line Amplifier
LOS	Loss of Signal
MI	Modulation Instability
NPN	Non-linear Phase Noise
NRZ	Non-Return to Zero
OA	Optical Amplifier
OAM	Operation, Administration and Maintenance
OAN	Optically Amplified Network
OAR	Optically Amplified Receiver
OAT	Optically Amplified Transmitter
OFA	Optical Fibre Amplifier
OFDM	Optical Frequency Domain Multiplexing
PA	Pre-Amplifier
PDH	Plesiochronous Digital Hierarchy
PDL	Polarization Dependent Loss
PHB	Polarization Hole Burning
PM	Phase Modulation
PMD	Polarization Mode Dispersion
PSK	Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
RZ	Return to Zero

SBS	Stimulated Brillouin Scattering
SDH	Synchronous Digital Hierarchy
SMF	Single-Mode Fibre
SNR	Signal-to-Noise Ratio
SOA	Semiconductor Optical Amplifier
<u>SOP</u>	<u>State of Polarization</u>
<u>SP</u>	<u>Single Polarization</u>
SPM	Self-Phase Modulation
SRS	Stimulated Raman Scattering
TRE	Terminal Receiver Equipment
WDM	Wavelength Division Multiplexing
XPM	Cross-Phase Modulation
<u>XPolM</u>	<u>Cross-Polarization Modulation</u>

5 Applications

Application of OAs in optical transmission systems offers a number of advantages. Chief among these advantages is the ability to realize very significant unrepeated system lengths as well as very long unregenerated system lengths. Deployment of OAs is likely to permit the retirement of many existing conventional regenerator sites and, in the case of new routes, to render unnecessary the construction of many new sites. OAs also enable serious consideration of new optical system architectures for application in terrestrial and submarine long haul, and access networks. Two examples of this are wavelength division multiplexing and point-to-multipoint applications, approaches heretofore generally considered prohibitively complex and expensive. OAs also offer potential advantages with respect to network upgrade options due to their independence from modulation format and bit rate.

However, the application of OAs also brings to light some new and potentially serious system impairments, which result from the high power levels produced by the OAs and the long distances between regeneration. These transmission effects include optical fibre non-linearities, polarization effects and effects due to the amplification characteristics of the OA itself. Chromatic dispersion also becomes increasingly significant for the long unregenerated systems enabled by the OA. In addition to determining chromatic dispersion limitations, the dispersion characteristics of the fibre influence the severity of the impairment produced by several of the dominant non-linear effects. As a result, dispersion management has been considered in system design. In the following clauses, the OA applications are described and important considerations for each application are identified.

If the characteristics are longitudinally compatible, the OA devices specified in this Recommendation can also be used to increase the distance in ITU-T G.955 plesiochronous digital hierarchy (PDH) optical line systems (which are not transversely compatible). To ensure transverse compatibility between OA devices and synchronous digital hierarchy (SDH) equipments and to satisfy the requirements of the ITU-T G.690-series Recommendations, either ITU-T G.957 equipment in accordance with clauses 6.1 and 6.2.2 of [ITU-T G.957] or a transponder(s) may be used.

5.1 Booster (power) amplifier

The booster (power) amplifier (BA) is a high saturation-power OA device to be used directly after the optical transmitter to increase its signal power level. The BA does not need stringent

requirements for noise and optical filtering. The operation, administration and maintenance (OAM) functions for the BA may or may not be shared with the optical transmitter.

The application of BAs (often in conjunction with pre-amplifiers) is very attractive, especially in those cases where intermediate locations with active equipment are either undesirable or inaccessible, as in submarine systems. In any case, fewer intermediate locations imply easier maintenance for the network operator. The most direct and simple means to increase the available power budget is to use either a BA directly after the regular transmitter or an optically amplified transmitter (see clause 5.4).

Because of the relatively high level of input power, the undesirable amplified spontaneous emission (ASE) noise, inherently present due to the statistical process of photon generation inside the OA, is usually negligible. However, application of BAs may result in fibre non-linearity induced system penalties due to the high optical power levels produced by BAs and the long interactive lengths provided by the optical path.

5.2 Pre-amplifier

The pre-amplifier (PA) is a very low noise OA device to be used directly before an optical receiver to improve its sensitivity. The requisite low level of ASE noise may be achieved through the use of narrow-band optical filters. In this case, automatic tuning of the centre wavelength of the pre-amplifier filter to the transmitter wavelength would be advantageous, since it would permit the relaxation of requirements on both the initial transmitter wavelength tolerance and its long-term stability. As noted previously, the use of PAs (usually in conjunction with BAs) is a straightforward means to realize significant increases in available power budget. The OAM function for PAs may or may not be shared with the optical receiver. In STM-64 or higher level systems, the use of a PA-only configuration can be useful (e.g., to avoid potential problems due to fibre non-linearities).

5.3 Line amplifier

The line amplifier (LA) is a low-noise OA device to be used between passive fibre sections to increase the regeneration lengths or in correspondence with a multipoint connection to compensate for branching losses in the optical access network. As noted previously, line amplifiers might replace some or all conventional regenerators in long-haul fibre sections. It can be envisioned that more than one conventional regenerator can be replaced by a single LA, with the evident advantage of reduced equipment in transmission links. Furthermore, a situation can be envisaged where both line amplifiers for compensation of signal attenuation, and conventional regenerators for compensation of signal distortion, appear in long-distance networks.

A separate communication channel must exist in systems using LAs, which would allow alarming, supervision and control of the installed remote LAs. It is preferable for such a supervisory channel not to place restrictions on the selection of pump laser wavelength or operating window. Because each LA must be able to insert its own status and alarm information, the supervisory channel must be recovered, regenerated (with new information inserted) and retransmitted at each LA.

Theoretically, ultra-long (thousands of kilometres) transmission distances can be realized by periodically inserting line amplifiers in the optical path. However, in the case where many OAs are cascaded, deteriorated system performance can occur due to noise accumulation, spectral dependency of total gain, effects of polarization and chromatic dispersion and non-linear effects. Laboratory tests have shown that the overall system behaviour in the case of many cascaded line amplifiers is much more complex than that for the case of a few cascaded line amplifiers. In particular, the total gain of a chain of line amplifiers in series is generally peaked around a specific wavelength, depending on the specific amplifier configuration, giving considerable reduction of the usable OA operating wavelength range. Therefore, design of this type of system will be very much different from the situation with only a few cascaded line amplifiers.

5.4 Optically amplified transmitter

The optically amplified transmitter (OAT) is an OA subsystem in which a power amplifier is integrated with the laser transmitter, resulting in a high-power transmitter. The connection between the transmitter and the OA is proprietary and shall not be specified. The application considerations of OATs are generally the same as those for BAs (see clause 5.1).

5.5 Optically amplified receiver

The optically amplified receiver (OAR) is an OA subsystem in which a pre-amplifier is integrated with the optical receiver, resulting in a high sensitivity receiver. The connection between the receiver and the OA is proprietary and shall not be specified. The application considerations of OARs are generally the same as those for PAs (see clause 5.2).

5.6 Single-channel applications

BAs, PAs, LAs, OATs and OARs all find application in single-channel systems. In the case of single-channel transmission, noise accumulation can be reduced by using low noise OAs in combination with adequate band pass optical filtering. The dispersion limitations can be normally minimized by operating close to the fibre zero dispersion wavelength or by using suitable dispersion accommodation (DA) techniques. Furthermore, care must be taken to keep non-linear effects, like stimulated Brillouin scattering (see clause II.3.76) and self-phase modulation (see clause II.3.1), under control.

The main optical path interface parameter values for point-to-point, single-channel, long-haul synchronous digital hierarchy (SDH) systems utilizing OAs are described in the ITU-T G.690-series Recommendations. The reference configurations and functional characteristics of these systems are described in [ITU-T G.783].

5.7 Multi-channel applications

OAs also find application in multi-channel systems. In addition to the transmission impairments found in single-channel systems, multi-channel systems may also suffer degraded performance due to certain non-linear effects. These include four-wave mixing (FWM), cross-phase modulation (XPM) and potentially stimulated Raman scattering (SRS). As a result, special precautions must be taken when designing multi-channel systems to avoid or alleviate these impairments. In multi-channel systems using a series of LAs to provide long unregenerated lengths, the effects of cascaded amplifiers, especially the reduction of the usable gain spectrum, must also be considered.

The optical interface parameter values for point-to-point, multi-channel, long-haul SDH systems utilizing OAs are described in [ITU-T G.692]. The reference configurations and functional characteristics of these systems are described in [ITU-T G.783].

5.8 Point-to-point applications

Schemes of insertion of OA devices and subsystems in point-to-point applications are indicated in [ITU-T G.662] (see in particular, Figures 1, 2 and 3 of [ITU-T G.662]).

5.9 Point-to-multipoint applications

OAs can be used in optically amplified networks (OANs) to increase the optical power budget or to allow for higher splitting ratios in point-to-multipoint networks. Therefore, generally speaking, both power and line amplifiers will be used in these types of networks. The use of OAs in ring networks just before branching devices, in order to compensate for splitting/branching losses, is an example of a potential application.

NOTE – One of the first applications of the OAs may be for the distribution of video signals. In the case of analogue video systems, additional requirements compared to the ones of the OAs for digital applications are

necessary in order to maintain adequate carrier-to-noise ratio and avoid signal distortion. If AM modulated lasers are used, for instance, the OA gain must be very flat, in order to avoid frequency to intensity modulation conversions, leading to increased signal distortions. This effect can be minimized when using continuous wave (CW) operated lasers in combination with external modulators. In this way, polarization effects could be minimized too. Also, special care must be taken to keep OAs output power at acceptable levels in order to reduce non-linear effects like SBS.

6 Operation, administration and maintenance aspects

Certain considerations on operation, administration and maintenance (OAM) aspects of OAs are given in Appendix IV.

7 Parameter values and ranges for OFA devices

In this clause, parameter values of optical power amplifier (OFA) devices (BA, PA, LA) are provided, according to the lists given in clauses 7, 8 and 9 of [ITU-T G.662], with the aim of ensuring, as far as possible, optical transverse compatibility amongst OFA subsystems and OFA devices in point-to-point system configurations.

7.1 Booster (power) amplifier

7.1.1 Point-to-point

The output parameters for power amplifiers are system specific and are specified in the relevant system Recommendations (ITU-T G.690-series). Some example, input parameter values for power amplifiers can be found in Appendix I. The output parameters for power amplifiers, as described by the interfaces in the relevant system Recommendations, are assumed to be applicable for PDH systems as well.

7.1.1.1 Single-channel systems

Some example input parameter values for power amplifiers can be found in Appendix I. Output parameter values are specified in the ITU-T G.690-series Recommendations.

7.1.1.2 Multi-channel systems

Parameter values for power amplifiers to be used in digital multi-channel systems are for further study.

7.1.2 Point-to-multipoint

Because applications in point-to-multipoint architectures requiring power amplifiers are more likely to be analogue in nature, the associated parameter values are for further study.

7.2 Pre-amplifier

7.2.1 Point-to-point

The input parameters for pre-amplifiers are system specific and are specified in the relevant system ITU-T G.690-series Recommendations. Some example output parameter values for pre-amplifiers can be found in Appendix I. The input parameters for pre-amplifiers, as described by the interfaces in the relevant system Recommendations, are assumed to be applicable for PDH systems as well.

7.2.1.1 Single-channel systems

Some example output parameter values for pre-amplifiers can be found in Appendix I. Input parameter values are specified in the ITU-T G.690-series Recommendations.

7.2.1.2 Multi-channel systems

Parameter values for pre-amplifiers to be used in digital multi-channel systems are for further study.

7.3 Line amplifier

7.3.1 Point-to-point

7.3.1.1 Single-channel systems

Specific parameter values for line amplifiers in point-to-point single-channel systems are specified in the ITU-T G.690-series Recommendations.

7.3.1.2 Multi-channel systems

Specific parameter values for line amplifiers in point-to-point multi-channel systems are for further study.

7.3.2 Point-to-multipoint

Because applications in point-to-multipoint architectures requiring line amplifiers are more likely to be analogue in nature, the associated parameter values are for further study.

8 Parameter values and ranges for OFA-related aspects of OFA subsystems

8.1 Optically amplified transmitter

Parameter values for optically amplified transmitters for single-channel systems are specified in the ITU-T G.690-series Recommendations.

8.2 Optically amplified receiver

Parameter values for optically amplified receivers for single-channel systems are specified in the ITU-T G.690-series Recommendations.

9 Environmental conditions

Various classes of environmental conditions are specified in [IEC 60721-3-0]. Further details can be found in [IEC 60721-3-1] for storage, [IEC 60721-3-2] for transportation, [IEC 60721-3-3] for stationary use at weatherprotected locations, and [IEC 60721-3-4] for stationary use at non-weatherprotected locations.

10 Optical safety aspects

Under certain conditions (fibre break, open connectors), the optical output power of an OA may become accessible and may be hazardous to the human eye. Special precautions and requirements for installation and use of optical systems (including amplifiers) and a description of viewing aids are given in [IEC 60825-2].

Due to the high level of optical power involved, mainly in booster amplifiers and OATs, optical safety and optical surge generation issues (i.e., protection of personnel and equipment) are of primary relevance in line systems using OA devices and subsystems.

An appropriate procedure for automatic power reduction (APR), restart and safe operation of OAs is given in [ITU-T G.664].

Appendix I

Parameter values and ranges for OFA devices in single-channel point-to-point systems

(This appendix does not form an integral part of this Recommendation.)

In this appendix, example parameter values for OFA devices (BA and PA) are shown for single-channel point-to-point systems. These parameter values are according to the lists given in clauses 7 and 8 of [ITU-T G.662] and were developed to ensure, as far as possible, compatibility with parameter values specified in [ITU-T G.957].

As indicated in clause 7, optical interface specifications for the main optical path are provided by the ITU-T G.690-series Recommendations.

I.1 Booster (power) amplifier

The parameter values given in Table I.1 are examples of a minimum list of relevant input parameters (as given in [ITU-T G.662]) for power amplifiers in point-to-point single-channel systems. Only the input parameters have been included in the table, since the output parameters are system specific and are specified in the ITU-T G.690-series Recommendations.

Table I.1 – Input parameters for power amplifiers in single-channel systems

Parameter	Unit	Value
Input power range	dBm	–6/+3
Reverse ASE power level	dBm	≤–20
Input reflectance	dB	≤–27
Pump leakage	dBm	≤–15 (Note)
Maximum reflectance tolerable at input	dB	–27
Power wavelength band	nm	1530-1565
NOTE – The measured value of –15 dBm (max) takes into account all of the contributions coming from the power distribution around the peak value down to 30 dB below the peak value itself.		

I.2 Pre-amplifier

The parameter values given in Table I.2 are examples of a minimum list of relevant output parameters (as given in [ITU-T G.662]) for pre-amplifiers in point-to-point single-channel systems. Only the output parameters have been included in the table, since the input parameters are system specific and are specified in the ITU-T G.690-series Recommendations.