ETSI TECHNICAL REPORT

ETR 126

March 1994

Source: ETSI TC-TM

Reference: DTR/TM-01019

ICS: 33.080

Key words: Amplification, fibre, optical, network

Transmission and Multiplexing (TM); Applications of optical fibre amplifiers in long distance and optical access networks

ETSI

European Telecommunications Standards Institute

ETSI Secretariat

Postal address: F-06921 Sophia Antipolis CEDEX - FRANCE
Office address: 650 Route des Lucioles - Sophia Antipolis - Valbonne - FRANCE
X.400: c=fr, a=atlas, p=etsi, s=secretariat - **Internet:** secretariat@etsi.fr

Tel.: +33 92 94 42 00 - Fax: +33 93 65 47 16

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Foreword

This ETSI Technical Report (ETR) has been produced by the Transmission and Multiplexing (TM) Technical Committee of the European Telecommunications Standards Institute (ETSI).

This ETR describes possible applications of optical fibre amplifiers in long distance and optical access networks.

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1 Scope

This ETSI Technical Report (ETR) describes possible applications of Optical Fibre Amplifiers (OFAs) in both long distance and Optical Access Networks (OANs). The impact of applying OFAs in both installed systems and systems under development are also discussed.

Descriptions given in this ETR are as general as possible, in order to allow the deployment of OFAs in both the 1 310 nm and the 1 550 nm wavelength regions.

Because of current commercially available technology the emphasis of this ETR is on OFAs using rare-earth doped fibres as the active medium operating in the 1 550 nm wavelength region.

2 References

For the purposes of this ETR, the following references apply:

[1] ITU-T Recommendation G.661 (1993): "Definition and test methods for the relevant generic parameters of optical fibre amplifiers".

[2] ITU-T Recommendation G.652 (1993): "Characteristics of a single-mode optical fibre cable".

[3] ITU-T Recommendation G.653 (1993): "Characteristics of a dispersion-shifted single-mode optical fibre cable".

[4] EN 60825: "Radiation safety of laser products, equipment classification, requirements and user's guide".

[5] IEC-825: "Radiation safety of laser products, equipment classification, requirements and user's guide".

3 Abbreviations

For the purposes of this ETR, the following abbreviations apply:

AM	Amplitude Modulated
ASE	Amplified Spontaneous Emission
CATV	Cable Television
CW	Continuous Wave
LOS	Loss of Optical input Signal
OAM	Operation And Maintenance
OAN	Optical Access Network
OAR	Optically Amplified Receiver
OAT	Optically Amplified Transmitter
OFA	Optical Fibre Amplifier
ONU	Optical Network Unit (customer side)
PDH	Plesiochronous Digital Hierarchy
SBS	Stimulated Brillouin Scattering
SDH	Synchronous Digital Hierarchy
STM	Synchronous Transport Module
WDM	Wavelength Division Multiplexing

4 OFA classification

4.1 Types of OFAs

The following categories of OFAs are considered in this ETR:

a) power, post, or booster amplifier;

b) line amplifier;

c) pre-amplifier.

An overview of the three categories under consideration is given in figure 1.

This ETR only addresses discrete OFAs, leaving the so-called distributed amplifiers (lightly doped transmission fibres using "remote" pumping at terminal ends) outside the scope of this ETR. Furthermore, only uni-directional operation of OFAs is assumed.

As well as separate deployment of the above three options, various combinations are possible, e.g. power and pre-amplifier or power, pre-amplifier and line amplifier.

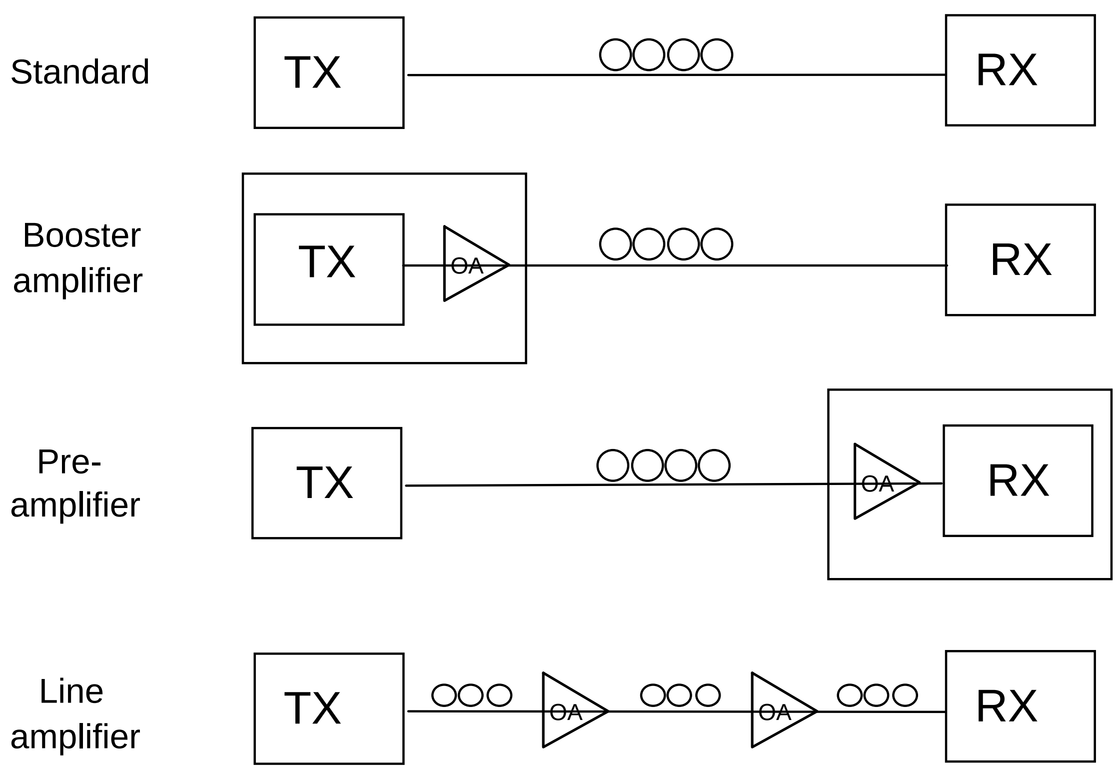

Figure 1: Overview of OFA categories

4.2 Power amplifier

A power, post-amplifier or booster amplifier is an OFA integrated with, or inserted in, the optical line just after a laser transmitter, where the first option results in an Optically Amplified Transmitter (OAT), and the second option results in a non-integrated optical power amplifier, as described in ITU-T Recommendation G.661 [1] (see figure 2). In the latter case, the OAM functions may or may not be shared with the optical transmitter. This OFA, operating most likely in a saturated mode, considerably increases the optical output power of commercially available laser sources. Furthermore, this OFA category does not need stringent requirements for noise and optical filtering. Because of the relatively high level of the OFA output power, the undesirable Amplified Spontaneous Emission (ASE) noise, inherently present due to the statistical process of photon generation inside the OFA, is usually negligible.

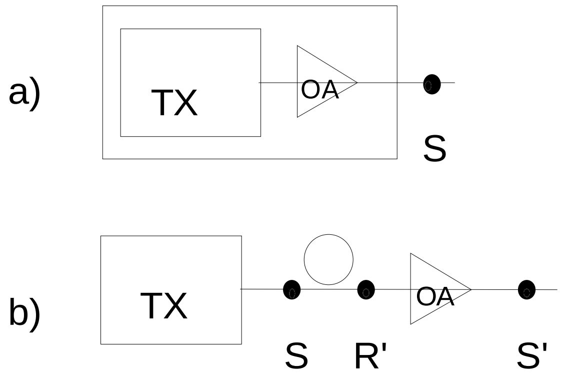

Figure 2: Scheme of the optical power amplifier as a) OAT; and b) non-integrated OFA

4.3 Line amplifier

A line amplifier is a low noise OFA, inserted between two passive fibre sections, in order to compensate for attenuation losses in long-haul fibre sections or to compensate for branching losses in point-to-multipoint OANs.

If designed properly, a line amplifier may replace a part of or all conventional regenerators in long-haul fibre sections. Depending on its capabilities, it can be envisioned that even more than one conventional regenerator can be replaced by a single line amplifier, 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 line amplifier should have a sufficient dynamic range to ensure practical deployment, related to existing ITU-T Recommendations.

4.4 Pre-amplifier

A pre-amplifier is a very low noise OFA, which improves the receiver sensitivity considerably, when being integrated with, or inserted in, the optical path just before the optical receiver. The first option will create an Optically Amplified Receiver (OAR), and the second option results in a non-integrated optical pre-amplifier as described in ITU-T Recommendation G.661 [1] (see figure 3). In the latter case, the OAM functions may or may not be shared with the optical receiver.

The required low level of the ASE can be achieved by using narrow band optical filters. An automatic tuning capability of the centre wavelength of the pre-amplifier filter to the transmitter wavelength is very much preferable in order to relax requirements on initial transmitter wavelength tolerance and its long-term stability.

The pre-amplifier, in combination with the optical receiver, should have a sufficient dynamic range to ensure practical deployment.

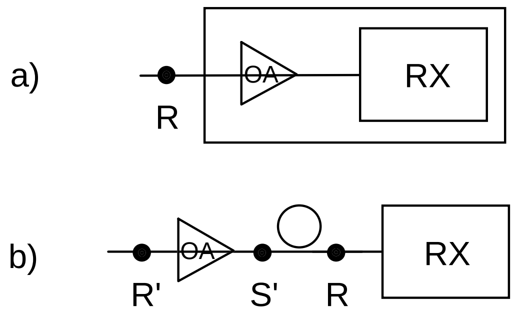

Figure 3: Scheme of the optical pre-amplifier as a) OAR; and b) non-integrated OFA

5 System aspects

Regarding maintenance and supervision, a distinction should be made between power amplifiers and pre-amplifiers on one side and line amplifiers on the other side.

In case of pre-amplifiers and power amplifiers, it is preferred that the OFA maintenance channels will be connected to the existing maintenance circuitry of the ordinary terminal equipment. This is trivial in the case of OATs and OARs. Therefore, dedicated service channels will not be necessary.

It is, however, mandatory to have a separate communication channel in case of line amplifiers, allowing alarming, supervision and control of installed remote line amplifiers. Such a supervision channel should be implemented in such a way that no restrictions of pump laser wavelength choices or operating wavelength window exist. One possibility is to superimpose a low-frequency Amplitude Modulated (AM) channel to the regular signal, but this will certainly have an impact on (existing) transmitter designs. Another option is to use a specific wavelength channel within or outside of the OFA operating wavelength window.

The number of fault information signals which could be taken into consideration should be limited and only related to the OFA as a "black-box", especially in the non-integrated cases e.g. Loss of Optical input Signal (LOS), OFA-degrade (increase of pump laser current above a fixed threshold) and OFA-fail (fatal failures, which can seriously degrade system performance, e.g. reduction of output power below a certain threshold).

Although some OFAs could be designed for a specific application, privileging the corresponding relevant characteristics, in general maintenance schemes (management and supervision) independent of the application are preferable. This allows the re-use of the OFA in case of system upgrading (when, for example, passing from PDH to SDH networks, or increasing the bit-rate, e.g. from STM4 to STM16, inserting line amplifiers into the installed equipment, or adding additional channels via WDM). However, some other approaches using embedded channels could be implemented.

6 Applications of OFAs in public telecommunication networks

6.1 General

OFAs can be generally applied in both long distance networks and in OANs with the enormous advantage of increasing the available power budget, allowing longer section lengths and higher splitting ratios respectively. Furthermore, OFAs are in principle transparent devices, independent of bit-rate, signal format and, therefore, ideally suitable for network upgrades.

6.2 Application of OFAs in long distance networks

In long-haul systems, the available power budget can be increased considerably by adding OFAs (power amplifiers, pre-amplifiers or line amplifiers) to the conventional terminal equipment. Especially in case of long-haul transmission the advantages of OFA application are evident, allowing not only upgrading from PDH to SDH, but also to higher bit-rates or even adding future wavelength channels within the same operating window. However, this upgrading is only possible if sufficient margins are available for the parameters involved (e.g. saturation output power, total dispersion of the line).

In general OFAs will compensate for attenuation losses in telecommunication networks. Therefore, systems which were attenuation limited at first, may now become dispersion limited. Nevertheless, OFAs can still offer longer section lengths on both standard, non-dispersion shifted fibres (ITU-T Recommendation G.652 [2]) as well as dispersion shifted fibres (ITU-T Recommendation G.653 [3]). Dispersion limits can occur sooner with dispersion-shifted fibres operated in the 1 310 nm wavelength region or non-dispersion-shifted fibres operated in the 1 550 nm wavelength region. However, several methods exist to minimize dispersion problems, e.g. using dispersion compensating fibres or Continuous Wave (CW) operated narrow-linewidth lasers with external modulators.

The application of power and pre-amplifiers proves to be very efficient in those cases, where intermediate locations with active equipment are either undesirable or inaccessible (i.e. like in submarine systems). Furthermore, less intermediate locations implies easier maintenance for the network operator. Therefore, the first, and by far the easiest, step to increase the available power budget is to use either an OAT (instead of a regular transmitter) or a power amplifier directly after the regular transmitter.

An equivalent increase in power budget can be realized by using an OAR or a pre-amplifier just before the conventional receiver. However, because pre-amplifier configurations are generally more complex than power amplifiers, due to the necessity of additional narrow band optical filters to reduce ASE levels, pre-amplifiers are likely to be used in combination with, rather than instead of, power amplifiers.

In general, system enhancement will be achieved by power amplifiers only, pre-amplifiers only, or a combination of both. Also, from a system point of view, these are the preferred configurations (see Clause 5). The use of line amplifiers should, therefore, be considered only in case of longitudinal compatibility or joint engineering, thus avoiding the difficult requirements related to transverse compatibility of communication channels between multi-source line amplifiers.

Theoretically, ultra-long (thousands of kilometres) transmission distances can be realized by periodically inserting line amplifiers in the optical path. However, when many OFAs are cascaded, problems can occur due to noise accumulation, spectral dependency of total gain, effects of polarization, chromatic dispersion and non-linear effects, causing deteriorated system performance. Laboratory tests have indicated that the overall system behaviour in the case of many cascaded line amplifiers is much more complex than in 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 a considerable reduction of the usable OFA operating wavelength range. Therefore, design for this type of system will be very much different from the situation with a few cascaded line amplifiers.

With respect to finding solutions to the above mentioned problems of cascading OFAs, a distinction should be made between single channel transmission and multiple wavelength channel transmission.

In case of single channel transmission, noise accumulation can be reduced by using low noise OFAs in combination with adequate band pass optical filtering. The dispersion limitations can usually be minimized by operating close to the fibre zero dispersion wavelength. Furthermore, care needs to be taken to keep non-linear effects under control, e.g. Stimulated Brillouin Scattering (SBS), (see subclause 6.3) and self phase modulation (changes of fibre index of refraction caused by high signal intensities).

When introducing multi-wavelength channels, new problems can occur due to insufficient gain uniformity and four wave mixing.

6.3 Application of OFAs in OANs

OFAs can be used in OANs to increase the optical power budget or to allow for higher splitting ratios in point-to-multipoint networks. Therefore, generally both power and line amplifiers will be applied in this type of network.

Using OFAs in ring networks just before branching devices, in order to compensate for splitting/branching losses, is an example of potential application.

One of the first applications of OFAs in OANs will be for the distribution of TV signals. In the beginning these systems may be analogue but they will gradually change into digital systems. In the case of analogue Cable Television (CATV) systems additional requirements, compared to OFAs for digital applications, are necessary in order to maintain adequate carrier to noise ratios. If AM lasers are used, for instance, the OFA gain should be very flat, in order to avoid frequency to intensity modulation conversions, leading to increased signal distortions. This effect can be minimized when using CW operated lasers in combination with external modulators. In this respect, polarization effects should be minimized, too. Also, special care should be taken to keep OFA output powers at acceptable levels in order to reduce non-linear effects like SBS. In this process, part of the optical signal is converted into a reverse propagating signal, reducing the power of the forward signal and increasing noise levels, with a decrease of the carrier to noise ratio.

7 Laser safety considerations

Under certain conditions (fibre break, open connectors) the optical output power of OFAs may be hazardous to the human eye. Special precautions should be taken to guarantee safe operation under all foreseeable operating conditions, taking EN 60825 [4] which is based upon IEC-825 [5]) into account.

Recently both IEC-825 [5] and EN 60825 [4] have undergone a major revision. In the revised standard the inherently safe Class 1 levels are 8,8 mW (+9,4 dBm) at 1 300 nm and 10 mW (+10 dBm) at 1 550 nm, while the limited safe Class 3A levels (safe without viewing aids) are 24 mW (+13,8 dBm) at 1 300 nm and 50 mW (+17 dBm) at 1 550 nm.

Appropriate safety mechanisms are currently under study.

History

Document history	
March 1994	First Edition
March 1996	Converted into Adobe Acrobat Portable Document Format (PDF)