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RESEARCH ARTICLE

# A COMPARISON OF OPTICAL AMPLIFIERS IN OPTICAL COMMUNICATION SYSTEMS EDFA, SOA AND RAMAN

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**ABSTRACT**

As the optical signal travels in a fiber waveguide, it suffers attenuation (loss of power). For very long fiber spans, the optical signal may be so attenuated that it becomes too weak to excite reliably the (receiving) photo detector, however the signal may be detected at an expected low bit error rate (-10-9 to _10- 11). To reach destinations that are hundreds of kilometers away, the optical power level of the signal must be periodically conditioned. Optical amplifiers are key devices that reconstitute the attenuated optical signal, thus expanding the effective fiber span between the data source and the destination.



## INTRODUCTION

In order to transmit signals over long distances (>100 km) it is necessary to compensate the attenuation losses within the fiber. Initially this was accomplished with an optoelectronic module consisting of an optical receiver, regeneration and equalization system, and an optical transmitter to send the data. Although functional this arrangement is limited by the optical to electrical and electrical to optical conversions. Several types of optical amplifiers have since been demonstrated to replace the OE– electronic regeneration systems. These systems eliminate the need for E-O and O-E conversions. This is one of the main reasons for the success of today’s optical communications systems shown in Figure 1.

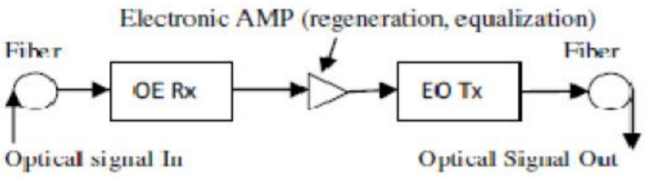


**Figure 1. Optical Communication System**

The transmission distance of optical fiber systems is generally limited by fiber losses. For long-haul systems, the loss limitation has traditionally been overcome using regenerators in which the optical signal is first converted into an electric current and then regenerated using a transmitter. Such regenerators become quite complex and expensive for wavelength division multiplexed (WDM) systems.

### Optical amplifiers

The general form of an optical amplifier:

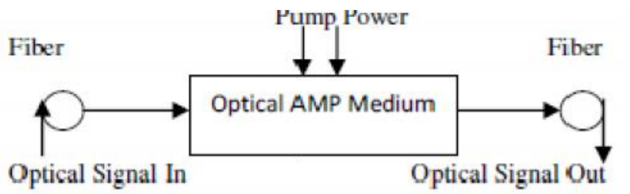


**Figure 2. Optical Amplifier**

Optical amplifiers (OAs) are devices based on conventional laser principles. They receive one or more optical signals, each within a window of optical frequencies and simultaneously amplify all wavelengths. The transmission distance of any fiber-optic communication system is eventually limited by fiber losses. For long-haul systems, the loss limitation has traditionally been overcome using optoelectronic repeaters in which the optical signal is first converted into an electric current and then regenerated using a transmitter. Such regenerators become quite complex and expensive for wavelength-division multiplexed (WDM) light wave systems. An alternative approach to loss management makes use of

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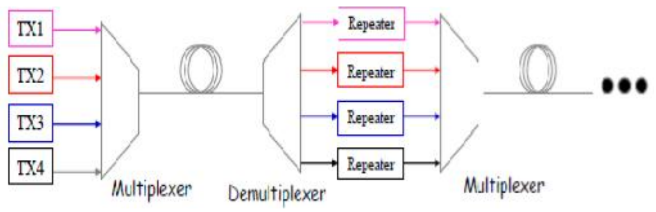
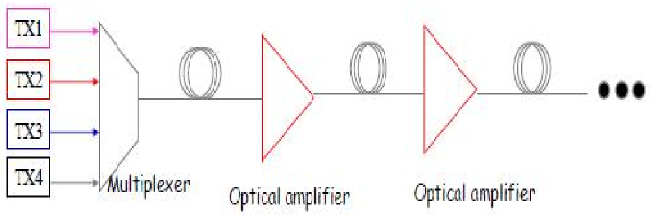
optical amplifiers, which amplify the optical signal directly without requiring its conversion to the electric domain.
These regenerators are complicated for WDM systems since each channel Needs its own repeater.




Optical amplifiers can in principle amplify all the channels simultaneously provided that they do not introduce cross talk




An optical amplifier is characterized by:

**Gain** – ratio of output power to input power (in dB)
**Gain efficiency** – gain as a function of input power (dB/mW)
**Gain bandwidth** – range of wavelengths over which the amplifier is effective
**Gain saturation** – maximum output power, beyond which no amplification is reached
**Noise** – undesired signal due to physical processing in amplifier

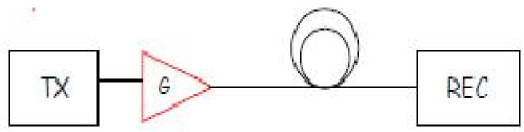
### Optical Communication Bands

| Band | Descriptor | Range (nm) |
|---|---|---|
| O band | Original | 1260 to 1360 |
| E band | Extended | 1360 to 1460 |
| S band | Short wavelength | 1460 to 1530 |
| C band | Conventional | 1530 to 1565 |
| L band | Long wavelength | 1565 to 1625 |
| U band | Ultralong wavelength | 1625 to 1675 |

### Application of optical amplifiers

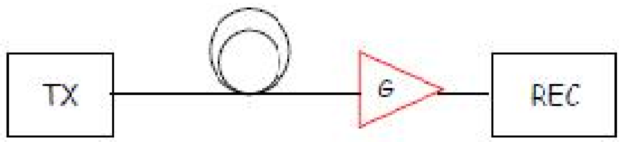
### 1. Booster amplifier

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.



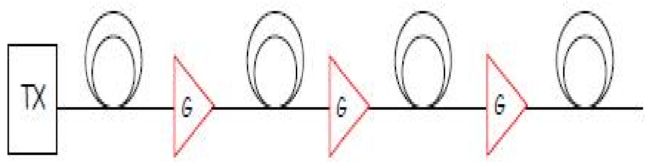

### 2. Pre-amplifier

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 narrowband optical filters




### 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.




### Types of optical amplifiers

There are several types of OAs. Among them: erbium-doped fibre amplifier (EDFA), semiconductor optical amplifiers (SOA), and Raman amplifiers. OAs require electrical or optical energy to excite the state of electron-hole pairs. Energy is typically provided by injecting electrical current (in SOA), or optical light in EDFA and Raman amplifiers.

### 1. EDFA-type amplifiers

An EDFA is a fibre segment, a few metres long, that is doped with the rare earth element erbium. The erbium ions may be excited by being pumped at a number of optical frequencies. The two more convenient excitation wavelengths are 980 nm and 1 480 nm. When these wavelengths propagate through the active fibre, erbium ions are excited and an incoming optical signal can be amplified by stimulated emission, releasing photon energy in the wavelength range 1 530- 1 565 nm (the C-band). By modifying the design of the amplifier, this range can also be shifted to longer wavelengths (the L-band). The basic structure of an EDFA consists of a coupling device, an erbium doped fibre and two isolators (one at each end) The fibre carrying the signal is connected via the isolator that suppresses optical reflections. The EDFA is stimulated by a laser source, known as the pump laser. The pump power (980 nm or 1 480 nm) is coupled into the EDFA together with the incoming data signal. The pump excites the fibre dopant ions, resulting in amplification of the data signal passing through at a wavelength in the 1 550 nm region.

## 2. SOA type amplifiers

The physical mechanism providing gain in semiconductor optical amplifiers (SOAs) differs in various aspects from that of the above EDFA amplifiers. Basically, SOAs are semiconductor lasers without the optical cavity feedback (the facets of the chip have an anti-reflection coating), and so the population inversion is generated in the active region by an electrical current. The stimulated emission of photons occurs via electron-hole recombination processes induced by the signal photons (at wavelengths included in the amplification band of the semiconductor material).

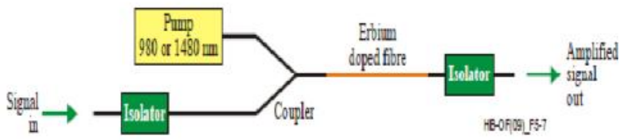



**Figure 3. An example of EDFA amplifier**

## 3. Raman amplifiers

Stimulated Raman Scattering (SRS) amplifiers are non-doped fibre amplifiers that employ high-power pumps to take advantage of the non-linear properties of the fibre .figure 4 shows how a fibre can be used as a Raman amplifier. The pump and the signal are injected into the fibre through a fibre coupler. The energy is transferred from the pump beam to the signal beam through SRS as the two beams co-propagate inside the fibre. The pump and the signal beams counter-propagate in the backward-pumping configuration commonly used in practice. Raman amplifiers are called distribute or discrete, depending on their design. In the discrete case, a discrete device is made by spooling 1-2 km of an especially prepared fibre. The fibre is pumped at a wavelength near 1.45 µm for amplification of 1.55 µm signals.

In the case of distributed Raman amplification, the same fibre that is used for signal transmission is also used for signal amplification. The pump light is often injected in the backward direction and provide gain over relatively long lengths (> 20 km). The most important feature of the Raman amplifiers is a large bandwidth range which can extend over the complete useful spectrum from 1 300 nm to 1 600 nm with no restriction to gain over bandwidth, thus enabling a multi-terabit transmission. On the negative side, Raman amplification require pump lasers with high optical power (> 1 W), with the related thermal management issues as
well as safety issues.

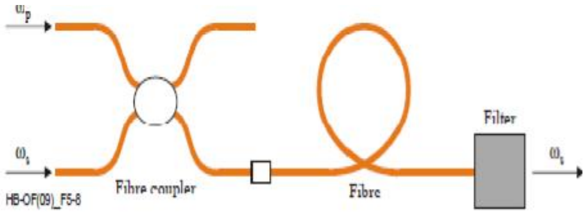



**Figure 4. Schematic of a Raman amplifier**

## Applications of EDFAs, SOAs and Raman amplifiers

EDFAs represent the most mature OFA technology and have been distributed on the market for several years and are produced by various manufacturers worldwide. The EDFA OA is particularly attractive for WDM optical systems and it is widely used for these applications. On the other hand, SOAs are still at the R&D stage. Today, very few manufacturers produce them and the yield is very low. Even though the technology of SOAs is based on the very well assessed semiconductor laser technology, several important problems related to packaging, pig tailing, anti-reflection coating and polarization sensitivity have not found yet satisfactory mass-scale production solutions. Moreover, field trials with SOAs have started recently and there is today only a limited

| Characteristic | EDFA | SOA | RAMAN |
|---|---|---|---|
| GAIN | >40 | >30 | >25 |
| WAVELENGTH | 1530-1560 | 1280-1650 | 1280-1650 |
| BANDWIDTH | 30-60 | 60 | Pump dependent |
| PUMP POWER | 25 dBm | <400 mA | >30 dBm |
| NOISE FIGURE | 5 | 8 | 5 |
| SIZE | Rack module | compact | Bulk module |
| SWITCHABLE | no | yes | no |
| COST FACTOR | medium | competitive | high |

| | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| EDFA | 1.A high power transfer efficiency | 1.Can only work at wavelengths where Er+3 fluoresces |
| | 2. Commercially available in C-band & L-band | 2. Requires specially doped fiber as gain medium |
| | 3. High gain | 3.Three-level system, so gain medium is opaque at signal wavelengths until pumped |
| | 4.Low noise figure | |
| | 5 Do not require high speed electronics. | 4.Requires long path length of gain |
| | 6. Immunity to cross talk | 5.Gain very wavelength dependent and must be |
| | 7. Suitable for long-haul applications. | flattened |
| SOA | 1. Compactness | 1. High coupling loss |
| | 2. Integration potential | 2. Polarization dependence |
| | 3. High power output | 3. High noise figure (as compared with EDFA) |
| | 4. Broad choice of operating wavelength (400-2000 nm) | 4. Polarization dependence |
| | 5. Low price with high volume production | 5. Cross-phase modulation |
| | | 6. Four-wave mixing and crosstalk |
| RAMAN | 1.variable wavelength | 1. Multipath interference 2.pump noise transfer 3.noise figure. |
| | 2. compatible with SM fiber | 4.gain control needed |
| | 3.can be used to extend EDFAs. | |
| | 4.Can result in a lower average power over a span | |
| | 5.good for lower crosstalk | |

experience in using SOAs in the field. At the present stage of the SOA technology, the most suitable applications of SOAs, as gain blocks in optical point-to-point systems, seem to be as booster amplifiers, integrated with the emitter laser, even though there are some limitations in terms of output power.

Problems related to line and pre-amplifier applications (such as polarization sensitivity and relatively high noise figure) are going to be solved. SOAs have a great potential as functional devices in optical switches, to simultaneously provide gain and fast gating functions, and in other signal processing devices (wavelength converters, optical multiplexers and demultiplexers), due to the strong non-linear response they have in the saturation regime. They can also be integrated in optical switch matrices to compensate for the losses internal to the matrix itself. Raman amplifiers are mainly used in long haul or ultra long haul transmission systems with very high capacity where the signal degradation coming from the noise of the EDFAs is not tolerable or the required optical bandwidth is larger then what an EDFA can support. Especially distributed Raman amplifiers can help to improve the optical signal-to-noise ratio (OSNR) by using the transmission fibre as active media. Due to the higher component cost, especially caused by the high pump power, this type of amplifier is not widely installed in today's network but furthermore dedicated for specific applications.

**Conclusion**

In this paper we made a comparison between optical amplifiers and their applications, SOAs offer certain advantages over more commonly used optical fiber amplifier such as low power consumption, compactness and non-linear gain properties. A particular attraction of EDFAs is their large gain bandwidth, which is typically tens of nanometers and thus actually more than enough to amplify data channels with the highest data rates without introducing any effects of gain narrowing. A single EDFA may be used for simultaneously amplifying many data channels at different wavelengths within the gain region; this technique is called wavelength division multiplexing. Before such fiber amplifiers were available, there was no practical method for amplifying all channels. The only competitors to erbium-doped fiber amplifiers in the 1.5-μm region are Raman amplifiers, which profit from the development of higher power pump lasers.

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Chapter 8 light amplifiers

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Optical amplification

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