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A review of the configuration and performance limitation parameters in optical amplifiers

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Optical amplifiers are realised in a wide range of applications, such as metro – dense wavelength division multiplexing and cable television networks. These applications require the amplifier to provide a maximum output power level by accepting an input power near the saturation level. To obtain an ideal amplifier according to several parameters, the erbium concentration in the composite core glass, the optimum length of the fibre, the pump saturation and the input signal signal-to-noise ratio must be critically studied and addressed. In this paper, we will review the types of optical amplifiers used in communication systems today as well as the parameters that limit the performance of optical amplifiers in the network, such as the noise figure, the gain saturation, the polarisation dependence gain and inhomogeneous broadening effects. Based on the performance limitation factor, we model the amplifier gain profile and the effect of the gain value on the network performance. Finally, we propose various configurations of an optical amplifier, and the advantages of each amplification technique are highlighted.

Keywords: semiconductor optical amplifiers (SOA), erbium-doped fibre amplifier (EDFA), Raman amplifier.

1. Introduction

The miracle year of optical telecommunication was marked by the introduction of a low noise erbium-doped fibre amplifier (EDFA) more than a decade ago [1, 2]. Indeed, the history of optical amplifiers is as old as that of lasers, the only significant difference being in the presence or absence of feedback elements, such as end mirrors or gratings [3]. A cavity is useful for the accumulation of all radiated photons and for mode selection. Only the selective modes that are defined by the cavity parameters will survive and then couple out from the mirror. While the laser was very much hailed as one of the greatest inventions of the 20th century, the optical amplifier remained almost in oblivion, but not because the optical amplifier had no place. When optical fibres became the choice of medium for data transmission, the electronic regenerator amplified signals in-line [4]. The electronic regenerator has many disadvantages, the most serious of which is that it must be synchronised with the data. One of principal reasons that the optical amplifier was so detested was that its overall noise characteristic was far from ideal, which significantly reduced its usefulness [5]. Therefore, when the EDFA, which has much improved noise characteristics and polarisation insensitivity, was introduced, the optical telecommunication industry immediately responded with enthusiasm. Modern optical networks utilise amplification in the following ways:

– Power boosters: many tunable laser designs output low optical power levels and must be immediately followed by an optical amplifier. (A power booster can use either a SOA or EDFA.)

– In-line amplifier: it allows signals to be amplified within the signal path.

– Wavelength conversion: it involves changing the wavelength of an optical signal.

– Receiver preamplifier: SOAs can be placed in front of detectors to enhance the sensitivity.

There are four main parameters that are used to determine the performance of the amplifier and four additional parameters to control the output performance. The measurement parameters are the output power, the noise figure, the gain and the output signal-to-noise ratio. Meanwhile, the controlled parameters consist of the dopant concentration, the doped fibre length, the input signal-to-noise ratio and the configuration.

Using a single optical fibre SMF-28, the maximum distance without regeneration is almost 70 km, and distances beyond that require the application of a single amplifier. Therefore, the optical amplifier is very significant in optical long haul networks, such as dense wavelength division multiplexing (DWDM) and coarse wavelength division multiplexing (CWDM), and less important in customer access networks. However, in certain applications, the use of an amplifier is suggested to increase the scalability and survivability of the network system [6–8].

2. Optical amplifier types

With the demand for longer transmission lengths, optical amplifiers have become essential components in long-haul fibre optic systems. Semiconductor optical amplifiers (SOAs), erbium-doped fibre amplifiers (EDFAs), and Raman optical amplifiers lessen the effects of dispersion and attenuation, which improves the performance of long-haul optical systems.

2.1. Semiconductor optical amplifiers

Semiconductor optical amplifiers (SOAs) are essentially laser diodes, without end mirrors, which have fibres attached to both ends. The end mirrors have been replaced with anti-reflection coatings. An anti-reflection coating is a dielectric thin-film coating that is applied to an optical surface to reduce the optical reflectivity of that surface within a certain wavelength range. SOAs amplify any optical signal from either fibre and transmit an amplified version of the signal out of the second fibre. SOAs are typically constructed in a small package, and they work for 1310 and 1550 nm systems. In addition, they transmit bidirectionally, which reduces the size of the device and is an advantage over regenerators of EDFAs. However, the drawbacks of SOAs include the high-coupling loss, the polarisation dependence, and a higher noise figure. Figure 1 illustrates the basics of a semiconductor optical amplifier.

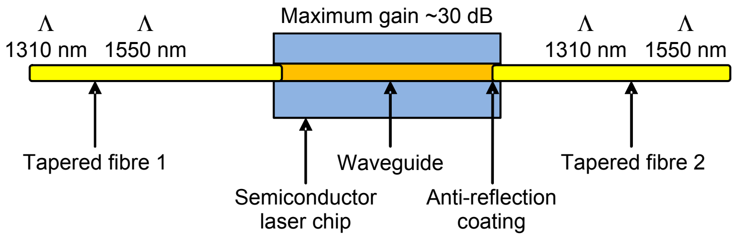

Fig. 1. Semiconductor optical amplifier.

The signal light is typically sent through a semiconductor single-mode waveguide with transverse dimensions of, *e.g.*, 1–2 μm and a length on the order of 0.5–2 mm. The waveguide mode has significant overlap with the active (amplifying) region, which is pumped with an electric current. The injection current creates a certain carrier density in the conduction band, allowing for optical transitions from the conduction band to the valence band. The gain maximum occurs for photon energies that are slightly above the bandgap energy. SOAs are often used in telecom systems in the form of fibre-pigtailed components and operate at signal wavelengths near 1.3 or 1.5 μm. They offer a gain of up to ≈30 dB. The technology of semiconductor amplifiers competes with that of EDFAs. The main differences between SOAs and EDFAs are that the setup of the SOA is considerably more compact: it contains only a small semiconductor chip with electrical and fibre connections and it is able to be integrated with other devices to create an opto-electronic integrated circuit (OEIC). The output powers are significantly smaller. The gain bandwidth is smaller, but devices operating in different wavelength regions can be made. The upper-state lifetime and thus the stored energy are much smaller, and thus the gain reacts to changes in the pump power or the signal power within nanoseconds (instead of milliseconds). The changes in the gain also cause phase changes (linewidth enhancement factor), but SOAs exhibit much stronger nonlinear distortions in the form of self-phase modulation and four-wave mixing. These distortions are often unwanted but can also be useful, *e.g.*, for optical signal processing. The noise figure of an SOAS is typically higher, and the amplification is normally polarisation-sensitive.

2.2. Erbium-doped fibre amplifiers

The dramatic increase of the number of applications of DWDM has made these optical amplifiers an essential building block for fibre optic systems. EDFAs allow information to be transmitted over longer distances without the need for conventional repeaters.

A relatively high-powered beam of light is mixed with the input signal using a wavelength selective coupler. The input signal and the excitation light must be at significantly different wavelengths. The mixed light is guided into a section of the fibre with erbium ions included in the core. This high-powered light beam excites the erbium ions to their higher-energy state. When the photons belonging to the signal at a different wavelength from the pump light meet the excited erbium atoms, the erbium atoms lose some of their energy to the signal and return to their lower-energy state. A significant point is that the erbium loses its energy in the form of additional photons, which are in exactly the same phase and direction as the signal being amplified. Therefore, the signal is amplified along its direction of travel only. This selectivity is not unusual – when an atom "lases", it always loses its energy in the same direction and phase as the incoming light, which is simply the way lasers work. Thus, all of the additional signal power is guided in the same fibre mode as the incoming signal. There is usually an isolator placed at the output to prevent the reflections from returning to the attached fibre. Such reflections disrupt the amplifier operation and, in the extreme case, can cause the amplifier to become a laser.

The fibre is doped with erbium, a rare earth element, which has the appropriate energy levels in its atomic structure to amplify light. EDFAs are designed to amplify light at 1550 nm. The device utilises a 980 or 1480 nm pump laser to inject energy into the doped fibre. When a weak signal at 1310 or 1550 nm enters the fibre, the light stimulates the rare earth atoms to release their stored energy as additional 1550 or 1310 nm light. This process continues as the signal travels down the fibre, gaining strength as it travels.

Photons amplify the signal by avoiding almost all active components, a benefit of EDFAs. Because the output power of an EDFA can be large, any given system design can require fewer amplifiers. Yet another benefit of EDFAs is their data rate independence, which means that system upgrades only require a change of the launch/receive terminals.

The most basic EDFA design amplifies light over a narrow, 12 nm band. The addition of gain equalisation filters can increase the band to greater than 25 nm. Other exotic doped fibres increase the amplification band to 40 nm. Because EDFAs greatly enhance the system performance, they find use in long-haul, high data rate fibre optic communication systems and cable television (CATV) delivery systems.

Long-haul systems require amplifiers because of the lengths of fibre used. CATV applications must often split a signal into several fibres, and EDFAs boost the signal before and after the fibre splits. There are four major applications that generally require optical fibre amplifiers: power amplifier/boosters, in-line amplifiers, preamplifiers and loss compensation for optical networks.

Below is a detailed description of each application. Figure 2 illustrates the first three applications for optical amplifiers. Power amplifiers (also referred to as booster amplifiers) are placed directly after the optical transmitter. This application requires

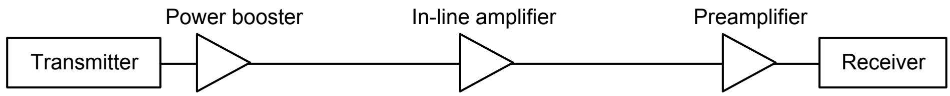

Fig. 2. Three applications for an EDFA.

that the EDFA take a large signal input and provide the maximum output level. The small signal response is not as important because the direct transmitter output is generally –10 dBm or higher. The noise added by the amplifier at this point is also not as critical because the incoming signal has a large signal-to-noise ratio (SNR).

In-line amplifiers or in-line repeaters modify a small input signal and boost it for retransmission down the fibre. Controlling the small signal performance and the noise added by the EDFA reduces the risk of limiting the length of the system due to the noise produced by the amplifying components.

In the past, a receiver sensitivity of –30 dBm at 622 Mb/s was acceptable; however, presently, the demands require a sensitivity of –40 or –45 dBm. This performance can be achieved by placing an optical amplifier prior to the receiver.

Boosting the signal at this point inputs a much larger signal to the receiver, thus easing the demands of the receiver design. This application requires careful attention to the noise added by the EDFA; the noise added by the amplifier must be minimal to maximise the received SNR.

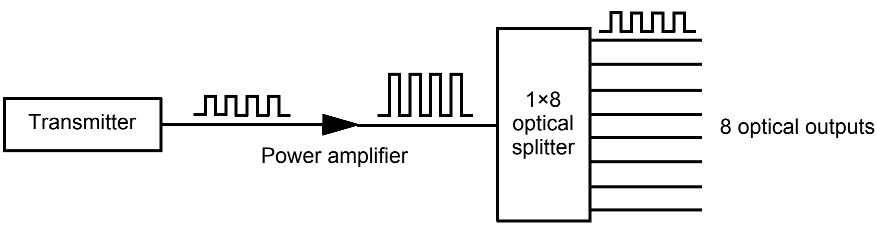

Fig. 3. Loss compensation in optical networks.

Compensating for loss in optical networks inserting an EDFA before an 8×1 optical splitter in a FTTH network increases the power, which allows each of the eight output legs to provide an acceptable dBm and makes the output almost equal to the original transmitter power. The optical splitter alone has a nominal optical insertion loss of 10 dB. The transmitter has an optical output of 10 dBm, meaning that the optical splitter outputs without an EDFA would be 0. This output power would be acceptable for most digital applications; however, in analogue CATV applications, this power is the minimal acceptable received power. Therefore, inserting the EDFA before the optical splitter greatly increases the output power (see Fig. 3). The EDFA is installed in the optical line terminal to increase the 1550 nm light, which is purposely used for video communication in a FTTH customer access network.

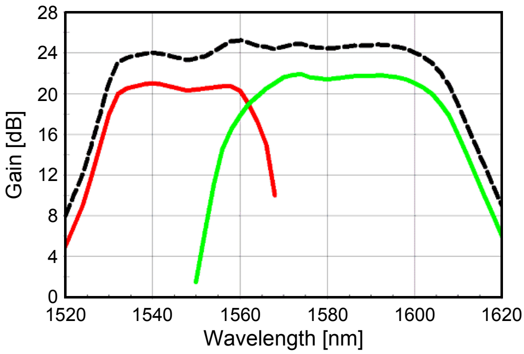

Fig. 4. Optical gain spectrum of a hybrid optical amplifier [9].

Wideband EDFAs optical communication systems that carry 100 or more optical wavelengths require an increase in the bandwidth of the optical amplifier to nearly 80 nm. Normally, the application of a hybrid optical amplifier, which consists of two separate optical amplifiers, allows for separate amplification, one for the lower 40 nm band and the second for the upper 40 nm band. Figure 4 shows an example of the optical gain spectrum of a hybrid optical amplifier, where solid lines illustrate the response of two individual amplifier sections. The dashed line, which was increased by 1 dB for clarity, shows the response of the combined hybrid amplifier.

2.3. Raman optical amplifiers

Raman optical amplifiers differ in principle from EDFAs or conventional lasers in that they utilise stimulated Raman scattering (SRS) to create optical gain. Initially, SRS was considered too detrimental to high channel count DWDM systems. Figure 5**a** shows the typical transmission spectrum of a six channel DWDM system in the 1550 nm window. All six wavelengths have approximately the same amplitude. By applying SRS to

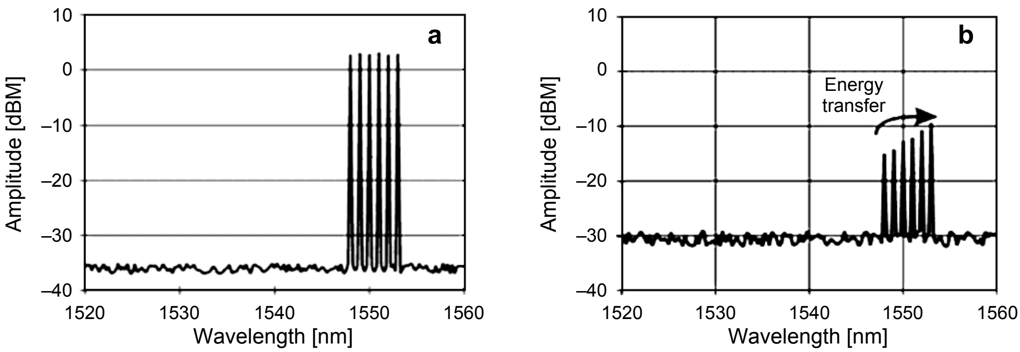

Fig. 5. DWDM transmit spectrum with six wavelengths (**a**), and received spectrum after SRS is on a long fibre (**b**) [10].

the wavelengths, the noise background increases, and thus the amplitudes of the six wavelengths become different (see Fig. 5**b**). The lower wavelengths have a smaller amplitude than the upper wavelengths. The SRS effectively robbed the energy from the lower wavelengths and fed that energy to the upper wavelengths.

A Raman optical amplifier is little more than a high-power pump laser and a wavelength division multiplexing (WDM) or directional coupler. The optical amplification occurs in the transmission fibre itself and is distributed along the transmission path. The optical signals are amplified up to 10 dB in the network optical fibre. The Raman optical amplifiers have a wide gain bandwidth (up to 10 nm). They can use any installed transmission optical fibre. Consequently, they reduce the effective span loss to improve the noise performance by boosting the optical signal in transit. They can be combined with EDFAs to expand the optical gain flattened bandwidth. Figure 6 shows the topology of a typical Raman optical amplifier. The pump laser and circulator comprise the two key elements of the Raman optical amplifier. In this case, the pump laser has a wavelength of 1535 nm. The circulator provides a convenient means of injecting light backwards into the transmission path with minimal optical loss.

Figure 7**a** illustrates the optical spectrum of a forward-pumped Raman optical amplifier. The pump laser is injected at the transmit end rather than at the receive end,

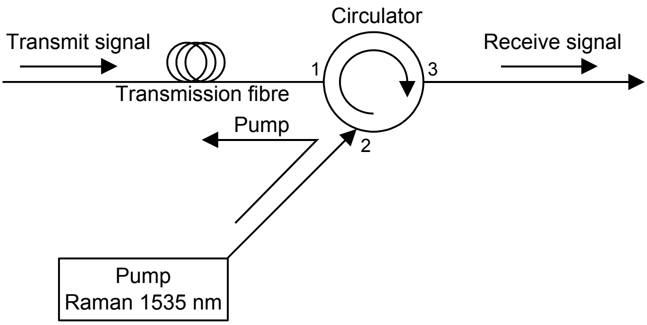

Fig. 6. Typical Raman amplifier configuration [10].

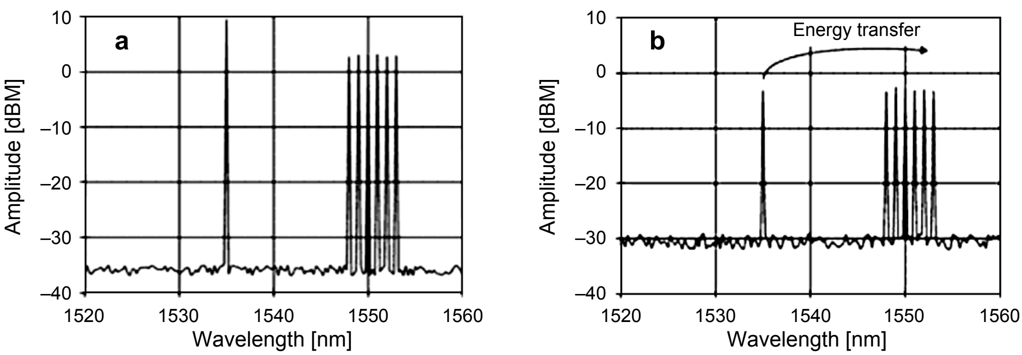

Fig. 7. Example of Raman amplifier transmitted (**a**) and received (**b**) spectrum [10].

as shown in Fig. 7**b**. The pump laser has a wavelength of 1535 nm, and the amplitude is much larger than the data signals. As before, applying SRS increases the amplitude of the six data signals significantly. The energy from the 1535 nm pump laser is redistributed to the six data signals.

Service providers have already installed millions of kilometres of the optical fibre networks with systems operating in the *C*- and *L*-bands (from 1539 to 1565 nm and from 1565 to 1625 nm, respectively), but the demand for bandwidth is increasing. The capacity can be increased by exploiting the *O*-band (from 1260 to 1360 nm). The gain achieved has been reported up to 10 dB with 100 nm [11]. Raman amplifiers have been suggested often for applications in CWDM networks, where the available wavelengths in *C*- and *L*-bands are limited [5, 12, 13].

3. Innovation configuration

The amplification gain also depends on the number of turns of the signal passing through the gain medium. Instead of amplifying the signal, the process has also been applied to noise. In addition to the materials used to build the fibre, the fibre length and the dopant ions, the configuration also plays a significant role in determining the profile gain performance [14]. Therefore, some innovation is required to introduce a new configuration, for example, for amplifier bidirectional communication signals and for doubling the amplification, as proposed in the next sub-topics, for EDFA and Raman amplifiers. However in the paper we are not covering the study on the innovation configuration but proposing the current research trend in the field.

3.1 Erbium-doped fibre amplifier

The combination of optical devices with EDFA can lead to exciting and excellent features. For example, the circulator used for the path management works effectively with EDFA to utilise an EDFA. Figure 8 shows the innovation in the configuration that uses an EDFA combined with a circulator to perform bidirectional single amplification (Fig. 8**a**) and double amplification (Fig. 8**b**). With this approach, the number of pump lasers and erbium-doped fibres can be reduced, which reduces the total installation cost of the network.

3.2. Raman amplifier

Raman amplifiers are being deployed in almost every new long-haul and ultralong--haul fibre-optic transmission systems, making them one of the first widely commercialized nonlinear optical devices in telecommunications. The device is experted to have advantages in improving the noise figure, reducing the nonlinear penalty of fibre systems, allowing for longer amplifier spans, higher bit rates, wide bandwidth, closer channel spacing, and operation near the zero wavelength. To maximize the impact, the configuration of Raman with the path management device by means of a circulator or coupler is applied. Figure 9 shows the configuration that uses an Raman combined with a circulator to perform standard bidirectional amplification two pumping (Fig. 9**a**) and bidirectional hybrid amplification (Fig. 9**b**). With this approach, the number of pump lasers and gain fibres can be reduced, which reduces the total installation cost of the network, and means less complexity as well as ease of maintenance.

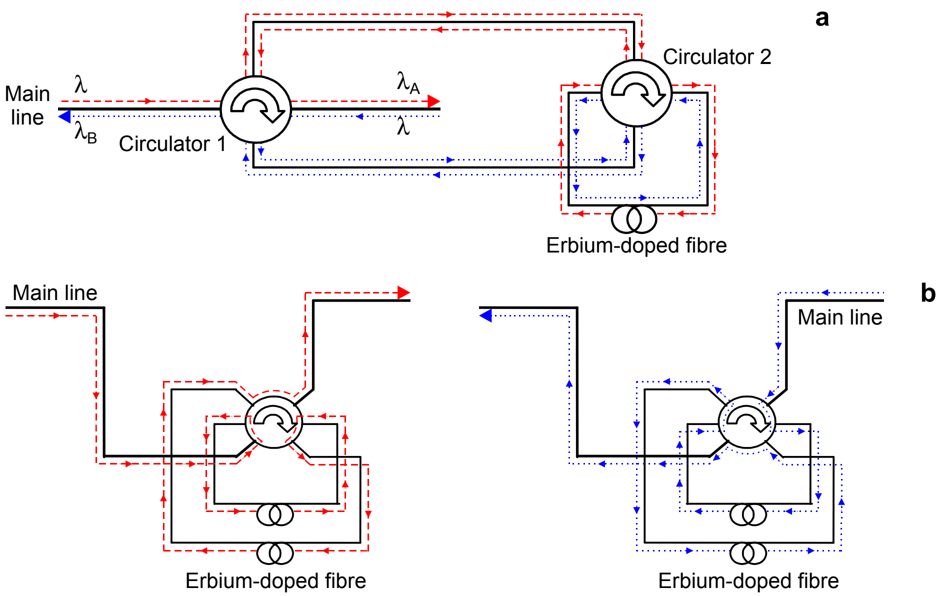

Fig. 8. Two configurations for bidirectional amplification using an EDFA and a circulator in combination: bidirectional amplification using single EDFA (**a**) and bidirectional double amplification (**b**).

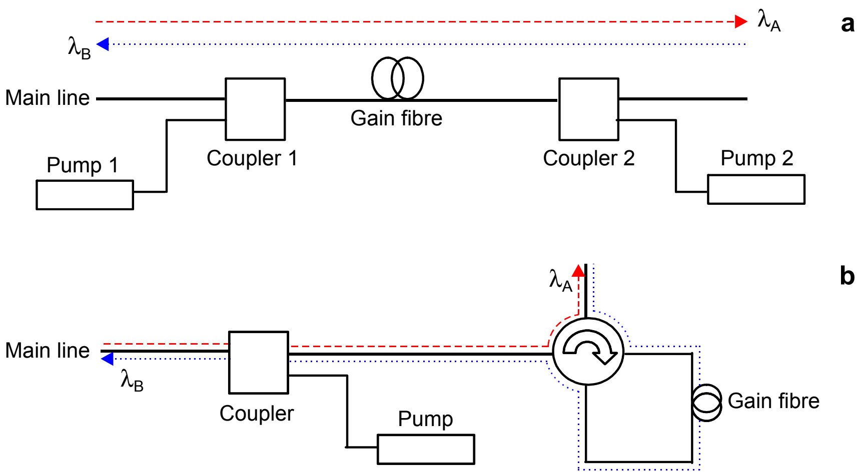

Fig. 9. Two configurations for bidirectional amplification using a Raman amplifier and a circulator in combination: standard bidirectional amplification two pumping (**a**), and bidirectional hybrid amplification (**b**).

4. Performance limitation factor

4.1. Noise

The noise performance of an optical amplifier is characterised by its noise factor (F) or, equivalently, the noise figure (NF). The noise factor is defined as the ratio of the input signal-to-noise ratio (SNR_{in}) to the output signal-to-noise ratio (SNR_{out}) while the noise figure is the noise factor expressed in dB [15]:

$$NF = 10\log\left(\frac{SNR_{in}}{SNR_{out}}\right)$$

In the field, it has long been known that the noise figure of a high-gain phase-insensitive linear optical amplifier cannot be smaller than 3 dB [16]. The 3-dB noise figure means that the SNR always degrades to less than half of the original SNR before amplification. For a long time, the noise figure of any optical amplifier was far from 3 dB; thus, the 3-dB quantum limit of the optical-amplifier noise figure was mostly a matter of academic interest. Because noise figures close to 3-dB have been reported for the past few years [6, 12], this limit is now of immense technological interest as well.

The principal source of noise in DFAs is amplified spontaneous emission (ASE), which has a spectrum that is approximately the same as the gain spectrum of the amplifier. ASE or superluminescence is light produced by spontaneous emission, which has been optically amplified by the process of stimulated emission in a gain medium. It is inherent in the field of random lasers. The noise figure in an ideal DFA is 3 dB, while practical amplifiers can have noise figures as large as 6–8 dB.

In addition to decaying via stimulated emission, electrons in the upper energy level can also decay by spontaneous emission, which occurs at random, depending upon the glass structure and the inversion level. Photons are emitted spontaneously in all directions, but a proportion of the photons will be emitted in a direction that falls within the numerical aperture of the fibre, and they are thus captured and guided by the fibre. The captured photons may then interact with other dopant ions and are thus amplified by stimulated emission. The initial spontaneous emission is therefore amplified in the same manner as the signals, hence the term *amplified spontaneous emission*. ASE is emitted by the amplifier in both the forward and reverse directions, but only the forward ASE has a direct effect on the system performance because that noise will co-propagate with the signal to the receiver, where it degrades the system performance. Counter-propagating ASE can, however, lead to the degradation of the performance of the amplifier because the ASE can deplete the inversion level, thereby reducing the gain of the amplifier.

The load line plays an important role in the optimisation of the performance of BER. The gain values that are less than the total loss (which can be called the load line) decrease the performance of BER linearly, but, if the gain is slightly greater than the load

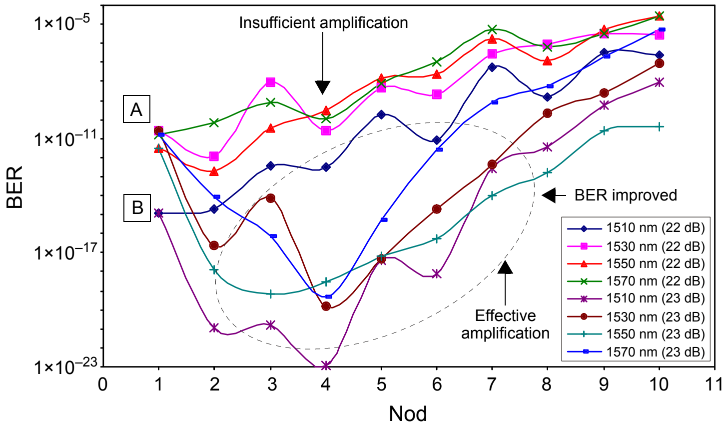

Fig. 10. The effects of sufficient and insufficient gain on the BER performance at every node in a ring optical network. The improvement in BER ensures that the maximum number of nodes can be extended [18].

line, the BER values are excited before they decrease linearly and slowly [17]. These effects are shown by the amplified signals of group A and group B, respectively. The total load line (loss) in the network is 22 dB. The BER performance is improved by increasing the output power. The suggested value for the EDFA gain is load line + 1 dB to represent sufficient gain [16]. The improvement (a gain of 23 dB) is clearly shown in Fig. 10, which compares it to the value of a gain that is less than the load line (22 dB). The SNR of the input signal is important for minimising the noise figure of the amplified signal [17]. Therefore, it is better to amplify the signal early to ensure a better SNR input. Thus, the noise figure can be minimised after the amplification because the amplification conceptually enhances the signal strength (amplitude) but not the signal recovery. The amplification performance also depends on the quality of the signal being amplified.

4.2. Gain saturation

Gain is achieved in a DFA due to the population inversion of the dopant ions. The inversion level of a DFA is primarily set by the power of the pump wavelength and the power at the amplified wavelengths. As the signal power increases, or the pump power decreases, the inversion level decreases, and therefore the gain of the amplifier decreases. This effect is known as gain saturation – as the signal level increases, the amplifier saturates and cannot produce any more output power, and therefore the gain decreases. Saturation is also commonly known as gain compression. To achieve optimum noise performance, DFAs are operated under a significant amount of gain compression (10 dB typically), which reduces the rate of spontaneous emission, thereby reducing the ASE. Another advantage of operating the DFA in the gain saturation region is that small fluctuations in the input signal power are reduced in the output amplified signal: the smaller input signal powers experience a larger (less saturated) gain while the larger input powers see less gain. The leading edge of the pulse is amplified until the saturation energy of the gain medium is reached. In some conditions, the width (FWHM) of the pulse is reduced.

The full width at half maximum (FWHM) is an expression of the extent of a function, given by the difference between the two extreme values of the independent variable at which the dependent variable is equal to half of its maximum value. The FWHM is applied to such phenomena as the duration of pulse waveforms, the spectral width of sources used for optical communications and the resolution of spectrometers. The term full duration at half maximum (FDHM) is preferred when the independent variable is time. The convention where "width" means "half maximum" is also widely used in signal processing to define the bandwidth as "the width of frequency range where less than half the signal's power is attenuated", *i.e.*, the power is at least half of the maximum. In signal processing terms, this level is at most –3 dB of attenuation.

We have examined the effect of gain saturation on the performance of the network. The amplitude signal of the amplified signal is fixed at a certain value, and the gain is increased continuously until the BER value shows the degradation due to the gain saturation. A few main parameters were fixed throughout the simulation, as shown in Table 1, and the profile of BER according to the gain value is shown in Fig. 10. The continuous increment of the amplifier has an inverse impact on the gain in the optical network due to the gain saturation. This effect can be observed through the BER value mentioned in the box.

Table 1. Parameters for the amplification value profile.

Parameter	Value
Distance between two nodes	60 km
Load line	15 dB + 10.4 dB = 25.4 dB
Sensitivity	–25 dBm
Thermal noise at receiver	3.1347×10^{-23} W/Hz
Rate of measurement	2.5 Gbps (OC-48)

According to Fig. 11, to achieve the optimum noise performance, the amplifiers are operated under a significant amount of gain compression because the gain reduces the rate of spontaneous emission, thereby reducing the ASE. Another advantage of operating the amplifier in the gain saturation region is that the small fluctuations in the input signal power are reduced in the output amplified signal: the smaller input signal powers experience a larger (less saturated) gain, while the larger input see less gain [19].

4.3. Inhomogeneous broadening effects

Inhomogeneous broadened effects are caused by the different ions in different glass locations, which exhibit different spectra. Due to the inhomogeneous portion of

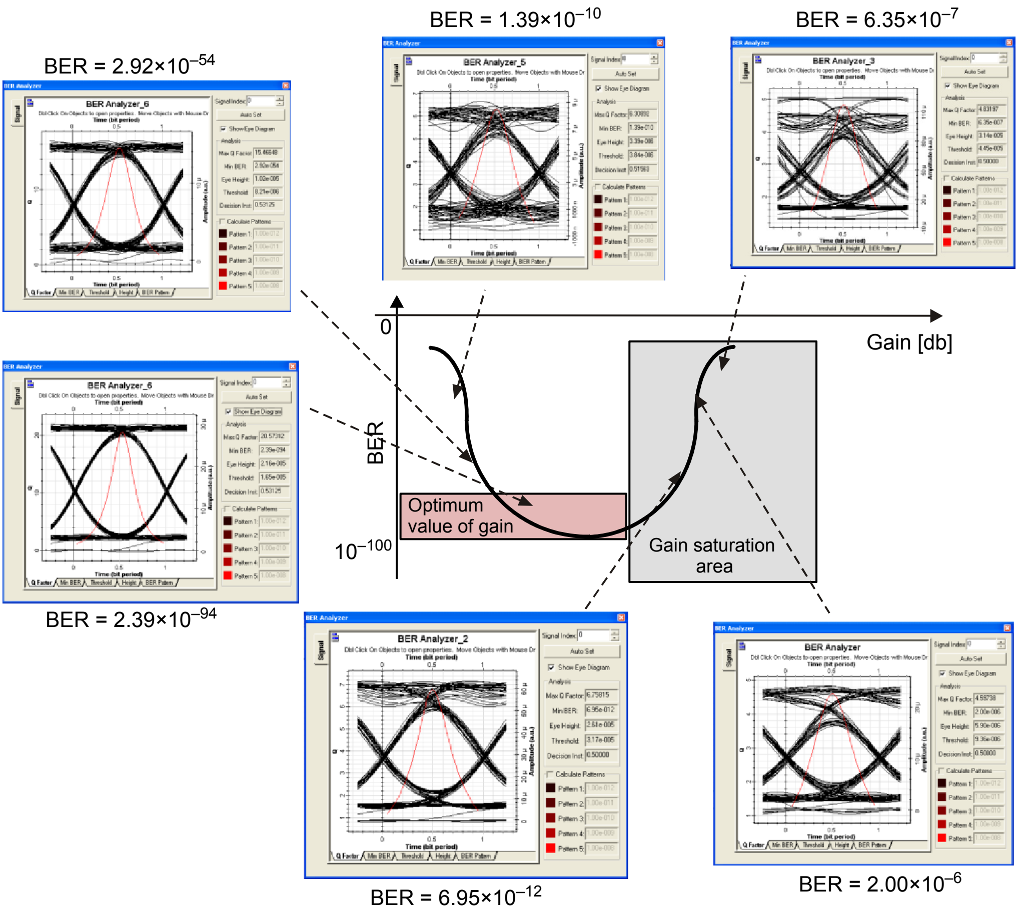

Fig. 11. BER profile *vs.* gain showing an extremely high area, which causes the performance degradation by means of gain saturation located at the right Gaussian profile.

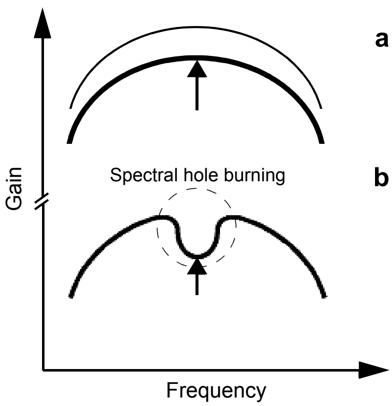

Fig. 12. The inhomogeneous broadening effects in the optical gain spectrum, before (**a**) and after (**b**).

the linewidth broadening of the dopant ions, the gain spectrum has an inhomogeneous component, and gain saturation occurs, to a small extent, in an inhomogeneous manner. This effect is known as spectral hole burning because a high power signal at one wavelength can "burn" a hole in the gain for wavelengths close to that signal by saturating the inhomogeneously broadened ions (see Fig. 12). The spectral holes vary in width depending on the characteristics of the optical fibre in question and the power of the burning signal, but they are typically less than 1 nm at the short wavelength end of the *C*-band and a few nanometers at the long wavelength end of the *C*-band. The depth of the holes is very small, though; thus, they are difficult to observe in practice.

4.4. Polarisation effects

Although the DFA is essentially a polarisation independent amplifier, a small proportion of the dopant ions interact preferentially with certain polarisations, and a small dependence on the polarisation of the input signal may occur (typically < 0.5 dB). This effect is called polarisation dependent gain (PDG). The absorption and emission cross sections of the ions can be modelled as ellipsoids with the major axes aligned at random in all directions at different glass sites. The random distribution of the orientation of the ellipsoids in the glass produces a macroscopically isotropic medium, but a strong pump laser induces an anisotropic distribution by selectively exciting those ions that are more aligned with the optical field vector of the pump. In addition, the excited ions aligned with the signal field produce more stimulated emission. The change in gain is thus dependent on the alignment of the polarisations of the pump and signal lasers, *i.e.*, whether the two lasers are interacting with the same sub-set of dopant ions. In an ideal doped fibre without birefringence, the PDG would be inconveniently large. Fortunately, in optical fibres, small amounts of birefringence are always present; furthermore, the fast and slow axes vary randomly along the fibre length. A typical DFA has several tens of meters, which is sufficiently long enough to show the randomness of the birefringence axes. These two combined effects (which, in transmission fibres, give rise to polarisation mode dispersion) produce a misalignment in the relative polarisations of the signal and pump lasers along the fibre, thus tending to average out the PDG. The result is that the PDG is very difficult to observe in a single amplifier (but is noticeable in links with several cascaded amplifiers).

5. Conclusions

According to this study, it can be concluded that the amplifier gain may affect the BER performance in the recovered area. Any changes in the power level can be compensated or improved by amplifier gain. Optimising the values can improve by extending the maximum length that can be achieved at minimum BER. Therefore, an optical amplifier configuration is vital to obtain a stable BER performance profile (slow decrement rate) in the secured optical ring network design. The relation between the BER performance and the amplification gain is in the form of a Gaussian negative. Hence, an area called extreme high/active (gain saturation) is created, where the increase in the gain value will degrade the value of the BER performance [16]. Therefore, research on the amplification value profile is very important to prevent the BER profile in the ring network from being in the extreme high/active area. The industry began exploring the new applications of amplifiers by introducing various specifications for devices. The features, such as the bandwidth, the band, the gain, safety, the speed, the tunability, the flexibility and the size, are the new goals for manufacturing. Various amplification devices have been produced to meet the communication requirements [20].

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