STUDY ON THE PERFORMANCE CHARACTERISTICS OF ERBIUM-DOPED FIBER AMPLIFIER FOR C AND L-BAND

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Abstract- Performance of Erbium-doped fibre amplifier is theoretically investigated using 980nm bidirectional pumping in a single-pass configuration. The optimum length of EDF in L-band and C-band is determined in this investigation. For the L-band, the optimum length of EDF was found to be 10m and for C-band, the optimum length was observed to be from 4m to 8m. The bidirectional pumping architecture was chosen over other architectures, such as forward and backward pump because it exhibits the highest possible gain (in dB). At input signal power of -20dBm, a maximum signal gain of 39.55dB is obtained at 1530nm. Moreover, the noise figure recorded is less than 6.78dB within the wavelength region from 1520 to 1610nm.

Keywords: Erbium-doped Fibre (EDF), Erbium-doped Fibre Amplifier (EDFA) and Dense Wavelength Division Multiplexing (DWDM).

1.0 Introduction

Erbium-doped Fibre Amplifier (EDFA) is an optical amplifier used exclusively in the communication field. It is used to amplify signals passing through a fibre optical cable. It was first discovered in the late 1980's and it was the first successful optical amplifier [1]. Modern fibre-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fibre, a cable containing bundles of multiple optical fibres that is routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal [2].

To overcome the attenuation or the loss in strength of the transmitted signals, the use of optical amplifiers is strictly recommended. This optical amplifier amplifies the optical signal directly without having to convert the signal into the electrical domain. It is made by doping a length of fibre with the rare-earth mineral erbium, and pumping it with light from a laser with a shorter wavelength than the communications signal, typically 980 nm [2].

The prolific growth of the Internet and data traffic has created an ever-increasing demand for transmission bandwidth of dense wavelength-division-multiplexing (DWDM) optical communication systems. The discovery of the EDFA has become one of the key components for DWDM transmission [3].

The schematic diagram of a simple Doped fibre Amplifier (DFA) is shown in Figure 1.

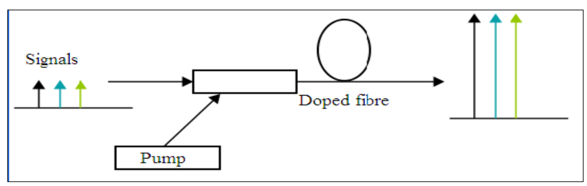

Figure 1: Doped fibre Amplifier

One of the main advantages resulted from the discovery of EDFA is that the distance between costly generators was extended and also an EDFA amplifies all the channels in a WDM signal simultaneously [1].

In this paper, the optimum length of EDF for both C-band and L-band is investigated as well as the best possible pumping architecture of EDFA. Lastly, the gain and noise figure characteristics of EDFA for input signal wavelength of 1520nm to 1610nm is examined using a bidirectional single-pass configuration. These studies are done using simulation software called OptiSystem.

2.0 Methodology

Several stages were involved in order to complete this project and are shown in the form of a flow chart in Figure 2.

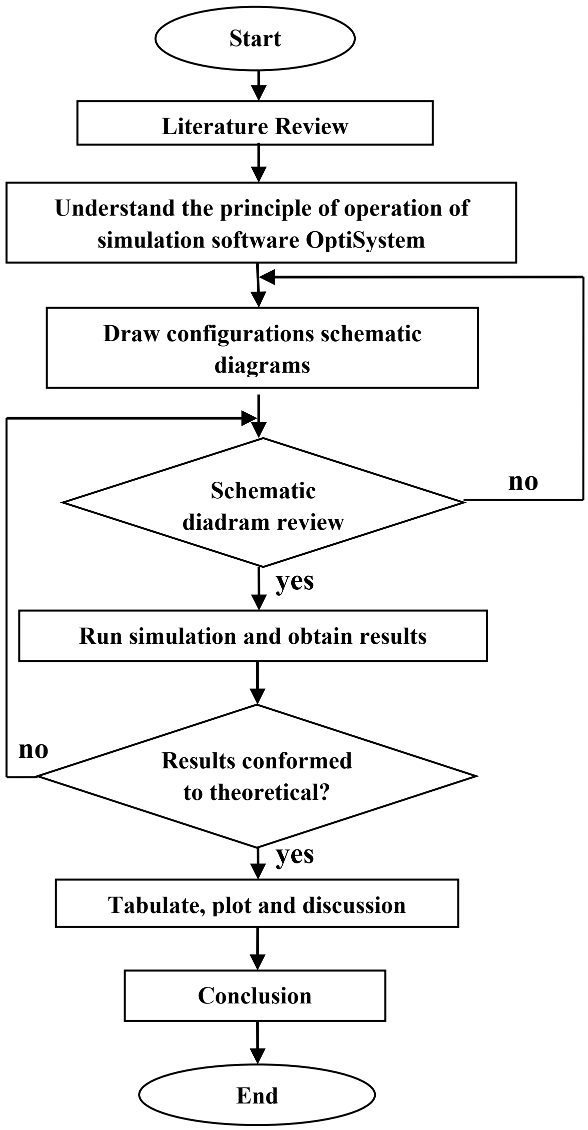

Figure 2: Flow chart of the methodology used in this project

The detail descriptions of the methodology used in this project were as below:

1) Literature review.
Literature review is the most important part of this project and was done at the beginning of the project. In this stage, the history and crucial information about Erbium-doped Fibre Amplifier (EDFA) was studied. The gathering of information has been done through reading of articles from the internet, journals and books.

2) Understand the principles of operation of simulation software OptiSystem.
The software that has been used for simulation purposes is called OptiSystem and the function of this software has been studied in order to understand the principles and how the simulation software works. The OptiSystem software contains a variety of components regarding optical communication system.

3) Draw configurations schematic diagrams.
Literature review and understanding the principles of simulation software is closely related so that adequate configurations can be drawn. The components needed were inserted and connected together to come up with the different types of configurations used in this project.

4) Run simulation and obtain results.
After the drawing of the configurations and is approved by the supervisor, simulation can be run and the results is recorded.

5) Tabulate, plot and discussion.
The results obtained from the simulation of the configurations are tabulated and plot using Microsoft Excel. Then, discussion is performed on the results and plots obtained based on the knowledge acquired in the literature review stage.

6) Conclusion.
Finally, a summary of the results obtained and discussions made is done and this completed the project.

3.0 Results and Discussion

3.1 Optimum length of EDF

Figure 3 shows the configuration used to determine the optimum length of EDF in both C-band (1550nm) and L-band (1580nm) applications. The length of EDF was varied from 5 to 25m.

For L-band, the signal input wavelength, signal input power, pump power and pump wavelength were 1580nm, -20dBm, 100mW and 980nm respectively. For C-band, the signal input wavelength, signal input power, pump power and pump wavelength were 1550nm, -20dBm, 100mW and 980nm respectively.

for this configuration. This is true for a given EDF ion concentration of 1×10^{25} ions/m^3.

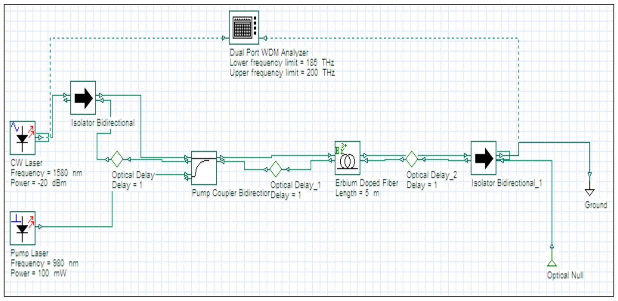

Figure 3: Configuration for determination of optimum length of EDF

Results obtained from the above configuration for L-band and C-band is shown in Figure 4 and Figure 5 respectively.

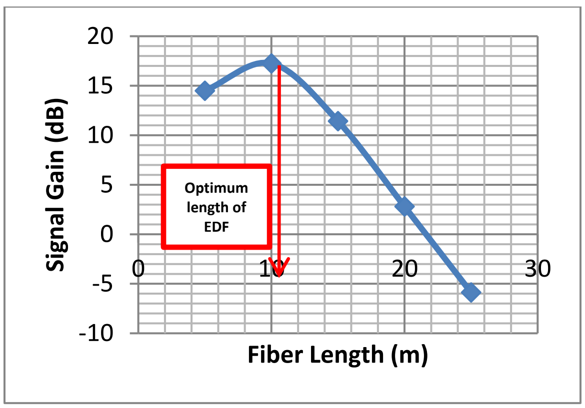

Figure 4: Varying length of EDF in L-band

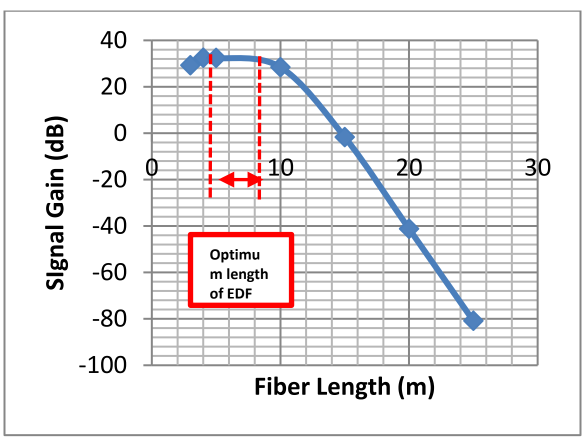

Figure 5: Varying length of EDF in C-band

The maximum gain of 32.49dB is attained in the C-band region with a 4m length of EDF. Therefore, the optimum length to be used in the C-band (1550nm) is 4-8m. In the L-band (1580nm), a maximum gain of 17.25dB was achieved using a 10m length of EDF. Hence, the optimum length of EDF in L-band is 10m

3.2 Study of pumping architectures in EDFA

In this part of the project, the best type of pumping architecture is studied. Three types of pumping architectures can be used in EDFA's, namely Forward/Co-propagating architecture, Backward/Counter-propagating architecture and Bidirectional architecture and their respective configurations are shown in Figure 6, 7 and 8.

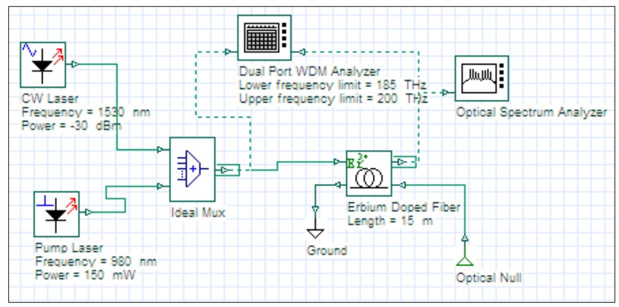

Figure 6: Forward/Co-propagating pumping architecture

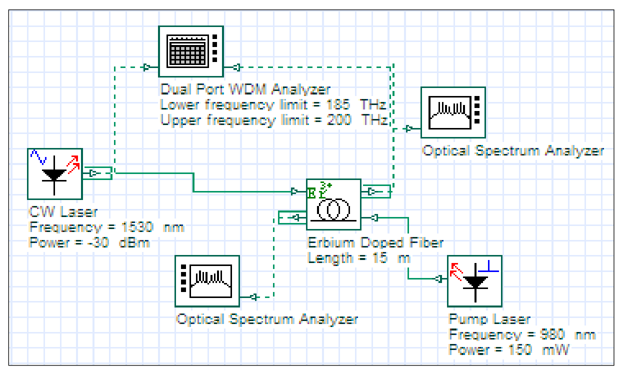

Figure 7: Backward/Counter-propagating pumping architecture

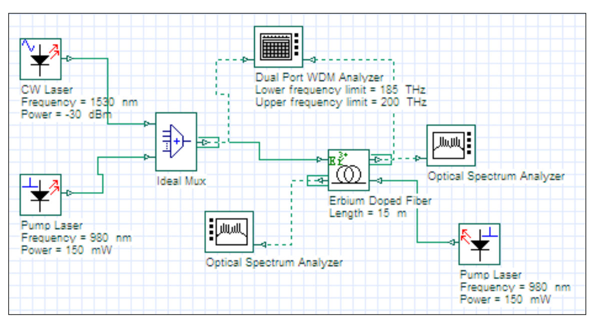

Figure 8: Bidirectional pumping architecture

The results from those configurations are shown in table 1.

	Gain (dB)	Noise (dB)
Forward/ Co-propagating pump	43.677	4.301
Backward/ Counter-propagating pump	43.708	10.553
Bidirectional pump	48.575	4.896

Table 1: Gain and noise figure for three configurations

Table 1 show that the maximum gain is realised with the Bidirectional pumping architecture as compared to forward and backward pumping architecture. However, when using the bidirectional pump, a noise figure of 4.9dB is obtained which is higher than that obtained when using the forward pumping architecture, which is 4.3dB but this value falls in the acceptable range for noise figure in EDFAs.

Noise figure in an ideal DFA is 3 dB, while practical amplifiers can have noise figure as large as 6–8 dB [6]. As well as 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 inversion level. Photons are emitted spontaneously in all directions, but a proportion of those will be emitted in a direction that falls within the numerical aperture of the fibre and are thus captured and guided by the fibre. Those photons captured 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' [6].

ASE is emitted by the amplifier in both the forward and reverse directions, but only the forward ASE is a direct concern to system performance since that noise will co-propagate with the signal to the receiver where it degrades system performance. Counter-propagating ASE can, however, lead to degradation of the amplifier's performance since the ASE can deplete the inversion level and thereby reduce the gain of the amplifier [6]. This is why backward pumping produces the highest noise figure among the three architectures.

3.3 Gain, noise figure and saturation characteristics of EDFA.

The overall performance of an EDFA is related to three main characteristics which are signal gain, noise figure developed by system and gain saturation [5].

Figure 9 shows the configuration used to investigate the performance characteristics of EDFA for DWDM systems.

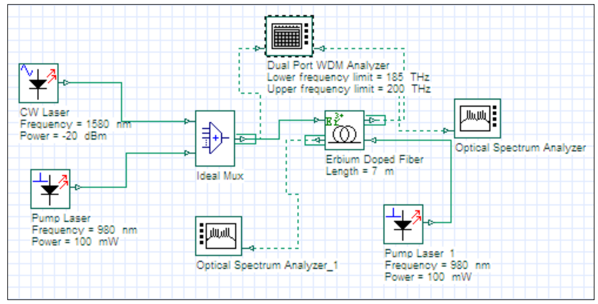

Figure 9: Single-pass configuration using bidirectional pumping architecture.

The above configuration is using the bidirectional pumping architecture so as to maximise the gain of the EDFA. From this configuration, three sets of data were taken. These are discussed in section 3.3.1, 3.3.2 and 3.3.3 of this technical paper.

3.3.1 Variation of input power from -20dBm to 5 dBm.

The variation of input power was done in order to determine the range of input power that should be supplied to the system. The fixed parameters used were input signal wavelength =1580nm; pump power = 100mW and pump wavelength = 980nm.

Figure 10 shows the different values of gain and noise figure obtained when varying input power from -20dBm to 5dBm.

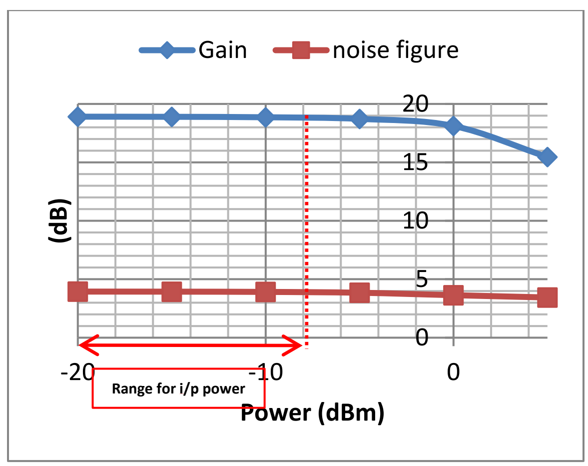

Figure 10: Variation of input power

From Figure 10, it can be noticed that the maximum gain of 18.9dB is achieved for input power range of

-20dBm to -8dBm. Beyond this point, the gain started to decrease gradually.

3.3.2 Variation of input wavelength

The variation of input wavelength was performed so that the gain and noise figure is obtained at different wavelength inside both C-band and L-band region, i.e. from 1520-1610nm. The fixed parameters used were input power = -20dBm, pump power = 100mW and pump wavelength = 980nm.

Figure 11 shows the different values of gain and noise figure obtained when varying the input wavelength from 1520 to 1610nm.

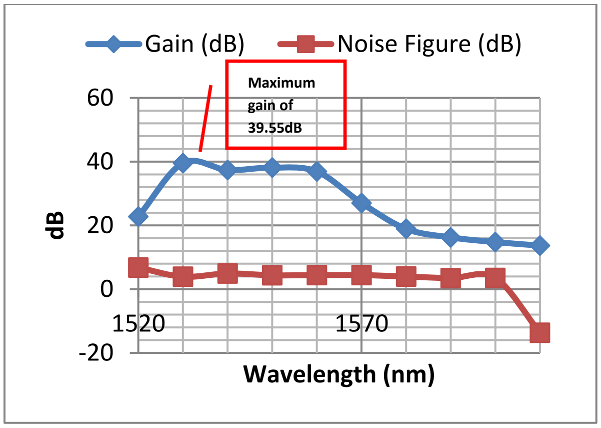

Figure 11: Variation of input wavelength

From Figure 11, it is observed that the variation of signal wavelength lead to a different value of gain and noise figure. The maximum value of gain is 39.55dB obtained at 1530nm of wavelength. This value is further supported by Amplified Spontaneous Emission (ASE) spectrum obtained by the Optical Spectrum Analyser (OSA). Figure 12 shows the ASE spectrum obtained for this experiment in which the maximum power output of -48dBm is recorded at 1530nm.

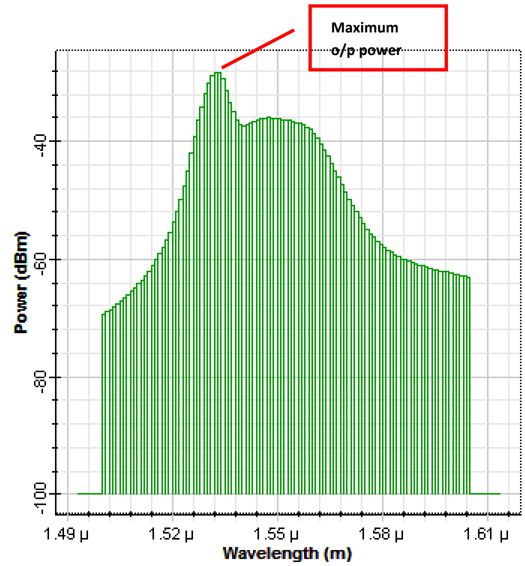

Figure 12: ASE spectrum

3.3.3 Signal gain vs pump power

In this experiment, the pump power that yield saturation gain is determined. The forward pump power is varied from 0 to 60mW. The following parameters were used in the simulation: signal wavelength for C-band (1550nm), Backward pump power fixed at 10mW and input signal power fixed at -20dBm.

Figure 13 shows the results obtained from varying the forward pump power.

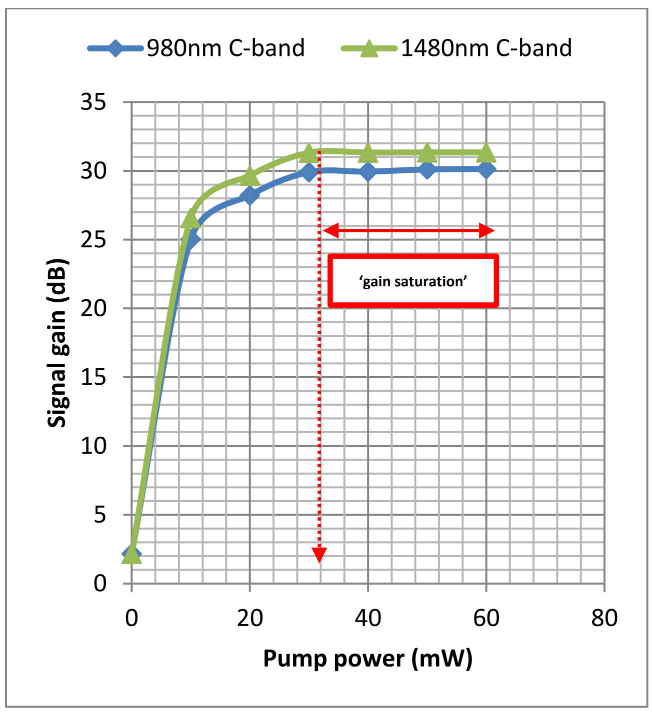

Figure 13: signal gain vs pump power

For C-band, gain saturation starts at 30mW for both 980nm and 1480nm pump laser. The highest gain of 31.4dB is achieved with the 1480nm pump laser.

Gain is achieved in a DFA due to population inversion of the dopant ions. The inversion level of a DFA is set, primarily, 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 will reduce and thereby the gain of the amplifier will be reduced. 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 reduces. Saturation is also commonly known as gain compression [6].

4.0 Conclusion

Upon completion of this project, it can be concluded that firstly, the optimum length of EDF is from 4 to 8m and 10m in C-band and L-band respectively. Secondly, bidirectional pumping architecture provides the highest gain among the three types of architecture (forward, backward and bidirectional) discussed. The most negative impact of backward pumping is that it can lead to the destruction of the EDFA despite showing an increase in signal gain. Lastly, it was observed that the maximum gain achieved by the bidirectional single-pass configuration is 39.55dB. At this point, the maximum gain achieved is 32dB for C-band using 980nm pump. Maximum output power occurs at 1530nm and can be distinguished in the ASE curve. Furthermore, 30mW of pump power will cause 'gain saturation' to occur using both 980nm and 1480nm pump laser for C-band.

5.0 Future Development

The use of Erbium-doped fibre amplifier is known to have compromised performance due to energy transfer during the up-conversion between Er^{3+} ions [3]. When power is supplied to an Erbium-doped fibre, the Er^{3+} ions undergo an increase in energy level. Therefore, these Er^{3+} ions become more unstable and lose some energy through amplified spontaneous emission to reach an energy level, known as metastable level. This phenomenon has a negative impact on the performance of Erbium-doped fibre amplifier. However, a host of new materials such as lanthanum-codoped bismuth-based fibre, tellurite-based fibre [4] and Ytterbium-codoped silica based fibre were proposed to enhance the amplification performance of EDFAs. It was found that bismuth-based Erbium-doped fibre (Bi-EDF) is the most effective since it exhibits an inherently broad emission spectrum and can be highly doped without suffering from the ion-quenching and clustering effects associated with the other proposed materials [3].

6.0 Acknowledgement

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7.0 References

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