Flat-gain and Wideband EDFA by using Dual Stage Amplifier Technique

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***Abstract*—In this paper, the flat-gain and wideband amplification of erbium-doped fiber amplifier (EDFA) was demonstrated by using a dual stage amplifier technique. The performance of dual stage amplifiers was investigated at high (-10 dBm) and low (-30 dBm) input signal powers and then compared with that of single stage amplifier performance in terms of varying length of the gain medium, pump power and input signal power. Both stages of amplifiers showed better amplification performance at low input signal power of -30 dBm, as compared to high input signal power of -10 dBm. The dual stage amplifier showed better amplification for all experiments in comparison with the single stage amplifier. The dual stage amplifier gave the highest gain from the gain medium the of 2 m and 20 m for EDF1 and EDF2, respectively, with the highest pump power of 700 mW. Succinctly, through the dual stage amplifier technique, flat-gain and wideband EDFA were significantly achieved.**

***Index Terms*—Dual Stage Amplifier; EDFA; Flat-gain; Wideband**

I. Introduction

In telecommunication systems, signal transmissions with high-speed data rate over long distances are unequivocally important. However, signal performance inevitably decreases due to high attenuation, fiber losses, and dispersion, which occur during the transmission process. Therefore, an improvement in gain performance is essential to solve and overcome the losses especially during signal transmission. The emergence of erbium doped fiber amplifier (EDFA) in the late eighties was one of the remarkable events in the history of optical communication. Effectively, the current development in optical fiber amplifiers like EDFA [1-4] and the such have allowed for better performance in transmitting data signals all over the world and is one of the solutions in overcoming signal losses during transmission in telecommunication systems. In addition, EDFAs possess the properties that can reduce data loss, i.e. high gain and low noise figure [2]. Basically, the performance of transmission signals is governed by these two factors, aside from system configuration and total pump power channeled to the system [3]. Therefore, to enhance the performance of EDFA in terms of gain amplification, various configurations need to be proposed such as single pass [4] [6], double pass [4] [6] [8], triple pass and quadruple pass schemes [5]. On the other hand, the researcher also attempts to improve the gain performance in terms of flat-gain and wideband amplification performance. In attaining flat-gain [6] and wideband performance, many researchers have been carried out with respect to EDFA, namely, double pass, gain-clamping, cascaded amplifier [7], hybrid amplifier and many more. An example of a cascaded amplifier is the dual stage amplifier, whereby it has two amplifiers in the configuration. But there is evidence, a lack of research on dual stage amplifiers. Thus, in this paper, the improvement of gain amplification for obtaining the flat-gain and wideband EDFA by using dual stage amplifier technique is proposed. The performance of this dual stage amplifier will then be compared with the performance of its single-stage counterpart, in terms of varying the length of the gain medium, pump power, and input signal power. The amplification performance is characterized in both the conventional band (C-band) and long band (L-band) [9] wavelength regions and simulated via OptiSystem simulator version 13 to determine the flat-gain and wideband EDFA.

II. Experimental Setup

In this research, two types of amplifiers are investigated, namely single and dual stage EDFA, using a computational simulation software; the OptiSystem version 13. OptiSystem is a comprehensive software design suite that enables users to plan, test, and simulate optical links in the transmission layer of modern optical networks. The results for both amplifiers are analyzed based on the amplification performance. In this regard, the results are verified by varying the length of the gain medium, pump power, and input signal power. There are two types of input signal powers investigated for amplification performance, which are the low and high inputs with values of 0 and -30 decibels (dB), respectively.

Figure 1 shows the design configuration of single stage EDFA. The configuration consists of a tunable laser source (TLS) acting as the input signal source, a variable optical attenuator (VOA), wavelength division multiplexing (WDM), erbium doped fiber (EDF), and optical spectrum analyzer (OSA). The WDM is used to combine the pump and direct it to the gain medium, EDF. OSA is used to characterize the amplification performance for this single stage EDFA.

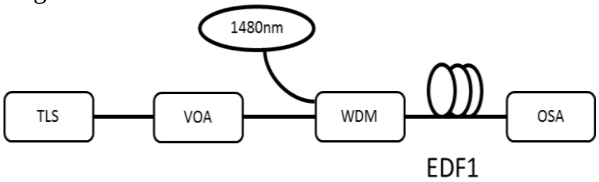


Figure 1: Configuration of Single Stage EDFA

Figure 2 shows the configuration for single stage EDFA simulated using OptiSystem software. The Continuous Wave (CW) Laser is also known as the TLS and generates a continuous wave optical signal. A Pump Laser is used as an optical amplifier pump. The Pump Laser transfers its energy or provides energy from an external source into the gain medium. The absorbed energy will produce excited states which cause population inversion that leads to amplification. For single stage EDFA configuration, the pump power is set to 100 mW with a wavelength of 1480 nm. A pump coupler combines the CW Laser and the Pump Laser. It is able to control the attenuation of the signal and the pump independently. The gain medium is a 2-m length EDF. The output of single stage EDFA is characterized and showed on the OSA and Dual Port WDM Analyzer.

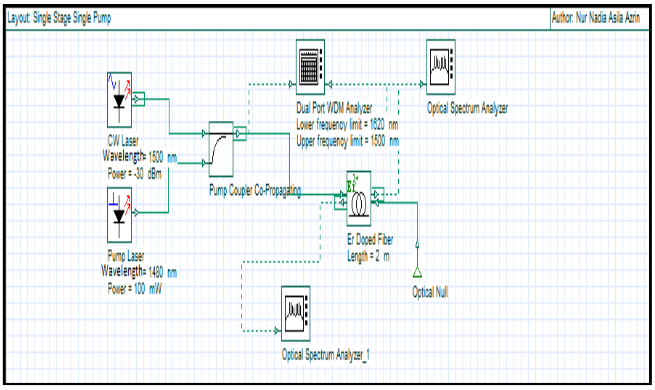


Figure 2: Simulation of Single Stage EDFA by using Optisystem

Figure 3 shows the configuration for a dual stage EDFA. This configuration is similar to that of single stage EDFA with the exception of an additional 1480-nm laser pump, WDM, and another gain medium. These additional equipment results in another amplifying stage, ergo, the dual stage EDFA.

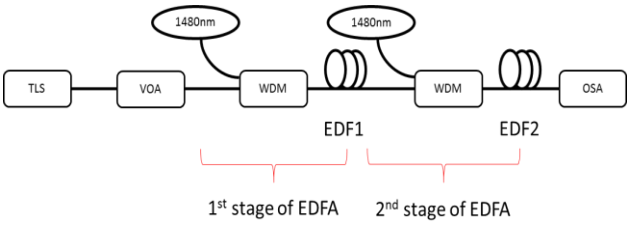


Figure 3: Configuration of Dual Stage EDFA

Figure 4 shows the simulation of the dual stage EDFA by using Optisystem version 13. This configuration is similar to that in Figure 2, but with an additional amplifying stage that consists of the pump laser, pump coupler, and EDF gain medium. For characterization of gain amplification, additional OSA and dual port WDM analyzer are needed.

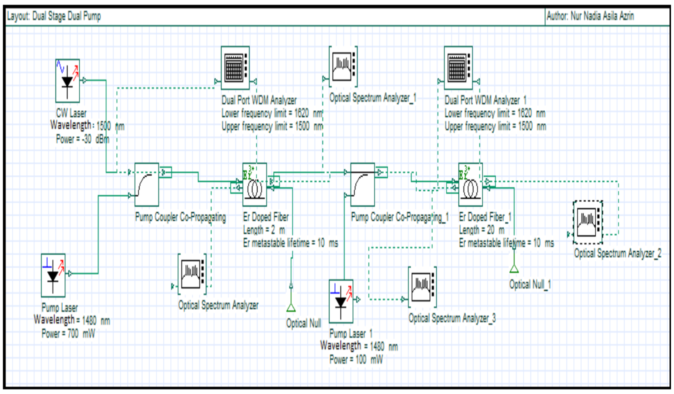
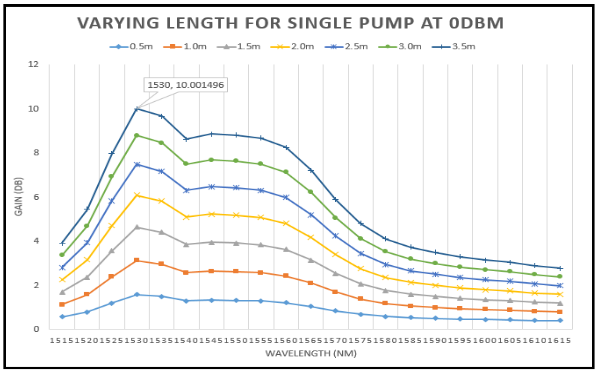


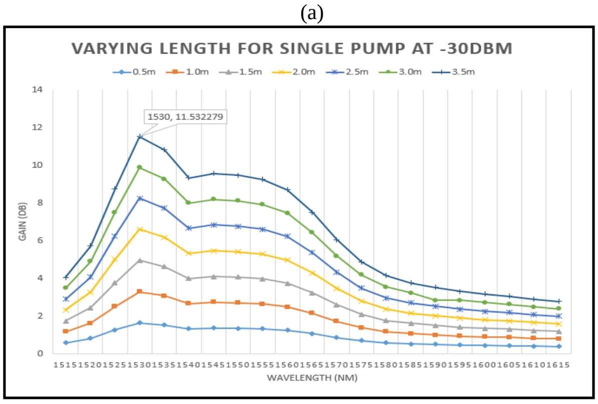
Figure 4: Simulation of Dual Stage EDFA by using Optisystem

III. Results And Discussion

In this section, the performance of gain amplification for both single and dual stage EDFAs were analyzed by varying the length of the gain medium, pump power, and input signal power. Figure 5 (a) and (b) show the gain performance for the single stage amplifier with low input signal power (-30 dBm) and high input signal power (0 dBm) using different lengths of the gain medium. The pump power was fixed at 100 mW with lengths varying at 0.5 m, 1.0 m, 1.5 m, 2.0 m, 2.5 m, 3 m and 3.5 m. The gain performance was characterized in the conventional band (C-band) and long band (L-band). The purpose of changing the length of the gain medium is to determine an optimal length such that the medium can give the highest gain performance. From the results, the longest gain medium length of 3.5 m gave the highest gain performance followed by 3.0 m, 2.5 m, 2.0 m, 1.5 m, 1.0 m and 0.5 m for both input signal powers. A simple conclusion drawn here is that the longer the length of the gain medium, the higher its gain performance. This was due to effective population inversion that occurred with longer gain medium especially at 1530 nm for both input signal powers, 0 and -30 dBm. The highest gain achieved at 1530 nm are 10.0 dB and 11.53 dB with input signals of 0 dBm and -30 dBm, respectively. The gain performance is higher at C-band wavelength region (1520 nm -1560 nm) and decreases when entering the L-band wavelength region (1565 nm – 1610 nm). This is because the gain medium is fully absorbed in the C-band wavelength region meanwhile no emission occurs in the L-band wavelength region.



(a)

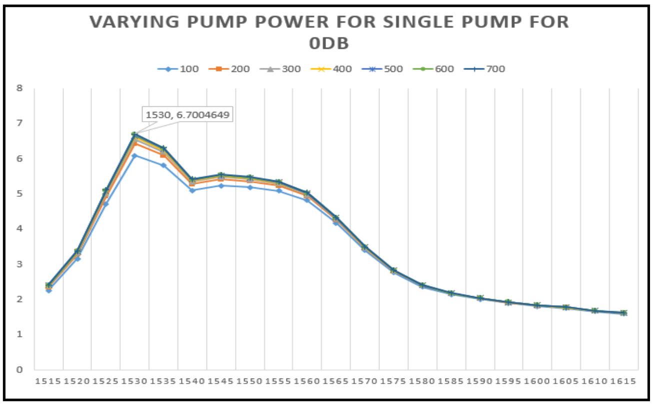


(b)

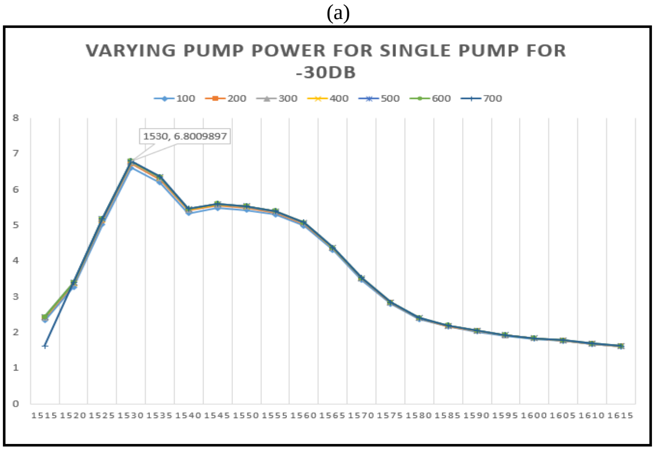
Figure 5: Gain performance for single stage EDFA by varying length of gain medium at (a) 0 dB (b) -30 dB

Figure 6 (a) and (b) show the gain performance for various pump powers for single stage EDFA with low and high input signal power, 0 dBm and -30 dBm. The pump power was varied from 100 mW, 200 mW, 300 mW, 400 mW, 500 mW, 600 mW, to 700 mW, with a fixed gain medium length of 2 m. The gain performance is characterized at C and L-band wavelength regions. Figure 6 (a) shows the graph of gain performance for single stage EDFA by varying pump power channeled at higher input signal power (0 dBm). The result shows that the highest pump power of 700 mW gives the highest gain, which is followed by pump power of 600 mW, 500 mW, 400 mW, 300 mW, 200 mW and 100 mW. In short, the higher the pumping power to the gain medium, the higher its gain performance. This results from erbium ions being excited to a higher level with higher pumping power, which increases emission. This increase in emission leads to higher amplification. The best achievable gain is at the highest pump power of 700mW, amounting to 6.7 dB, while the lowest gain is at the lowest pump power of 100 mW with only 6 dB.

Figure 6 (b) depicts the result of gain performance for varying pump powers with low input signal power (-30 dBm). As the pump power is increased from 100 mW to 700 mW, the highest gain achieved is at 1530-nm wavelength. The best gain is 6.8 dB at the highest pump power of 700 mW to the gain medium, whereas the lowest gain is 6.5 dB at the lowest pump power of 100 mW. When the pump power is continuously increased from 1515 nm, the gain also increased gradually up until 1530 nm. The pump begins to reach saturation after 1530 nm. For both figures, the gain performance is observed to be highly significant at the C-band region and starts to decrease when entering the L-band wavelength region. This is due to the inefficient population inversion that occurs in the L-band region. Moreover, it can be concluded that pump power affects erbium inversion levels, such that the higher the pumping power to the gain medium, the more excited the erbium ions thus causing the amplified signal to increase.



(a)

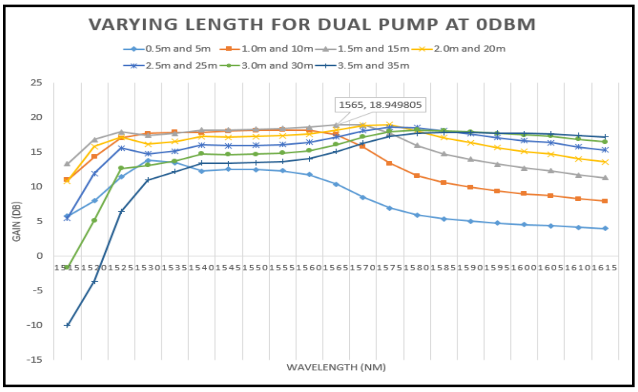


(b)

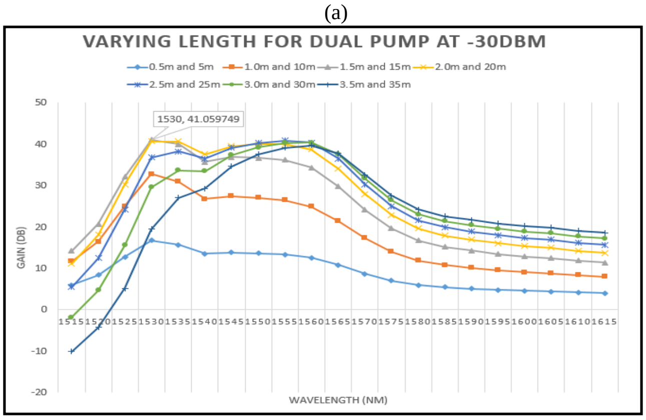
Figure 6: Gain performance for single stage EDFA by varying the pump power at (a) 0 dB (b) -30 dB

Figure 7 (a) and (b) shows the gain performance for dual stage amplifier investigated under high and low input signals of -30 dBm and 0 dBm for different lengths of the gain medium. The length of the gain medium is varied from 0.5 m, 1.0 m, 1.5 m, 2.0 m, 2.5 m, 3 m to 3.5 m for EDF1 and 5 m, 10 m, 15 m, 20 m, 25 m, and 30 m for EDF2. The pump power is fixed at 100 mW similar to that in the single stage amplifier. The performance of gain is characterized from 1510 nm to 1615 nm, which covers the C and L-band wavelength region. Table 1 shows the length of gain medium for single and dual stage EDFAs. Take note for the dual stage EDFA that the length of EDF2 is ten times longer than EDF1. The objective being that dual stage is meant to increase the gain performance at L- band region to achieve flat-gain and wideband amplification. In brief, EDF1 is for gain amplification at C-band wavelength region, while EDF2 is for gain amplification at L-band wavelength region. For amplification at L-band region, length of the gain medium should be ten times longer than that of the EDF1 to avoid full absorption at the L-band region that will lead to no gain amplification. Essentially, if EDF2 is longer, the gain amplification can be improved and is expected to increase.

In Figure 7 (a), the lengths of 2 m for EDF1 and 20 m for EDF2 are indeed the best results for gain amplification with the most flat-gain and wideband amplification. In Figure 7 (b), the length of 2 m for EDF1 and 20 m for EDF2 deliver the best gain performance within the wideband spectrum, but the gain is not as flat as the results with the higher input signal. Hence, it is deduced that the optimum length to achieve flat-gain and wideband amplification spectrum is 2 m for EDF1 and 20 m for EDF2.



(a)



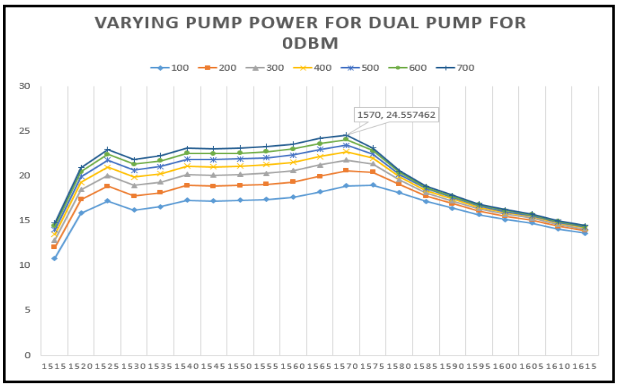
(b)

Figure 7: Gain performance for dual stage EDFA by varying length of the gain medium at (a) 0 dB (b) -30dB

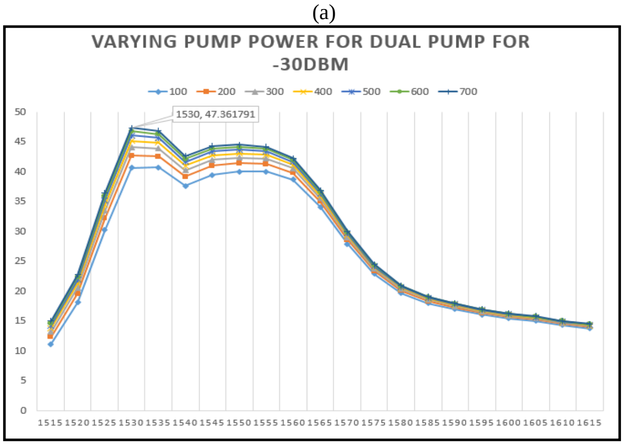
Table 1
Length of gain medium for single and dual stage EDFA

Varying length of EDF1 (m) for Single Stage EDFA	Varying length of EDF1 (m) and EDF2 (m) for Dual Stage EDFA
0.5	0.5 and 5.0
1.0	1.0 and 10.0
1.5	1.5 and 15.0
2.0	2.0 and 20.0
2.5	2.5 and 25.0
3.0	3.0 and 30.0
3.5	3.5 and 35.0

Figure 8 (a) and (b) show the gain performance of varying pump powers for dual stage amplifier with low and high input signals, 0 dBm and -30 dBm. Pump power is varied from 100 mW, 200 mW, 300 mW, 400 mW, 500 mW, 600 mW to 700 mW while the length of the gain medium is fixed at 2 m for and 20 m for EDF1 and EDF2, respectively. This length is selected based on the optimum result in Figure 7. The gain performance was investigated and characterized in C and L-band wavelength region. From Figure 8, lower input signal power gives better gain amplification performance than higher input signal power; however, at higher input signal power, the gain profile is better in terms of flatness of gain. Notwithstanding, both show better gain performance at highest pump power, 700 mW. From the results, it shows that with 0 dBm, the gain is highest at 1570 nm with 24.6 dB, meanwhile, at -30 dBm, the gain is highest at 1530 nm with 47.36 dB.



(a)



(b)
Figure 8: Gain performance for dual stage EDFA by varying the pump power at (a) 0 dB (b) -30dB

Figure 9 depicts the comparison between single and dual stage amplifiers with a varying gain medium for low and high input signal powers. The result is attained by taking the highest gains from both single and dual stage EDFAs. For a single stage, the highest gain was achieved at the medium gain length of 3.5 m, whereas for dual stage EDFA, the optimum lengths are 2m for EDF1 and 20 m for EDF2. The dual stage amplifier gives better gain performance compared with the single stage amplification. This is evidently due to the additional amplifier from the configuration that increases the emission, which leads to the increase in gain amplification. At lower input signal power, the gain performance is observed to be flatter and contributes to wideband amplification as compared to the high input signal power. This indicates that the population inversion effect is longer for smaller input signal power, whereas higher input signal power suppresses this effect and hence reduces the attainable gain.

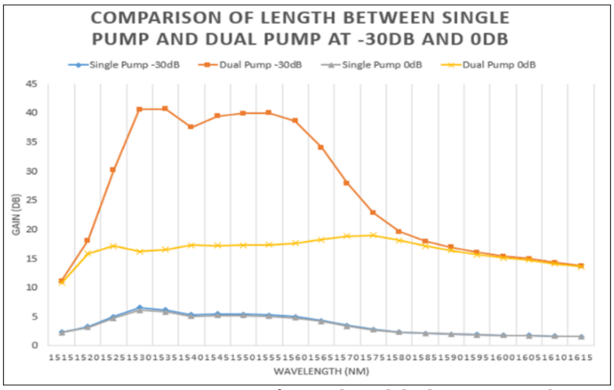


Figure 9: Gain comparison for single and dual stage EDFA by varying length of gain medium at 0 dB and -30 dB

Figure 10 shows the comparison of single and dual stage amplifiers with varying pump power at low and high input signal powers, -30 dBm and 0 dBm. The results show that the dual stage amplifier gives better gain performance than the single stage amplifier. This is obviously due to the dual stage amplifier having two amplifiers, both of which will optimize respective bands in contrast to the single stage amplifier which only has one amplifier to perform in either C or L-bands at a time. Besides this, the dual stage amplifier at higher input signals satisfy the objectives of the study, i.e. to attain flat-gain and wideband of EDFAs as compared to that of the single stage amplifier.

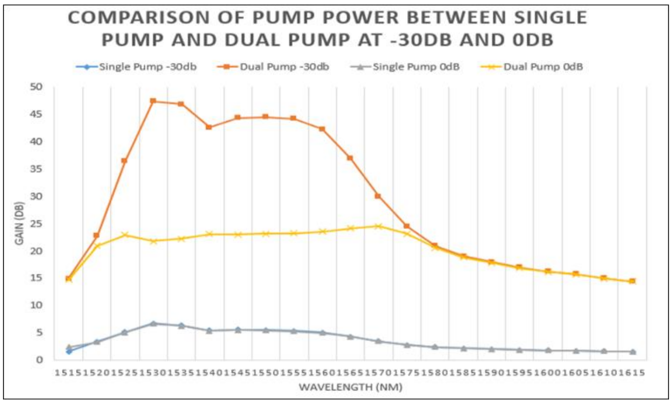


Figure 10: Gain comparison for single and dual stage EDFA by varying the pump power at 0 dB and -30 dB

Figure 11 shows the comparison between single and dual stage amplifiers with varying input signal power from -40 dBm to 20 dBm. Based on the results, the input signal power for dual stage amplifier delivers higher gain performance than its single stage counterpart but the gain seems to decrease as the input signal is increased. Though the gain performance is lower for the single stage compared to dual stage amplifiers, the gain is deemed flat from -40 dBm to 0 dBm. Concluding that the gain performance is higher at low input signal power than at high input signal power, the reason is pegged on the large difference between the output and input signal powers of the EDFA, as proven from Equation (1):

$$Gain\ (dB) = Pout\ (dBm) - Pin\ (dBm) \qquad (1)$$

The population inversion level is dependent on the output signal power, such that the inversion levels decrease as the input signal power is increased.

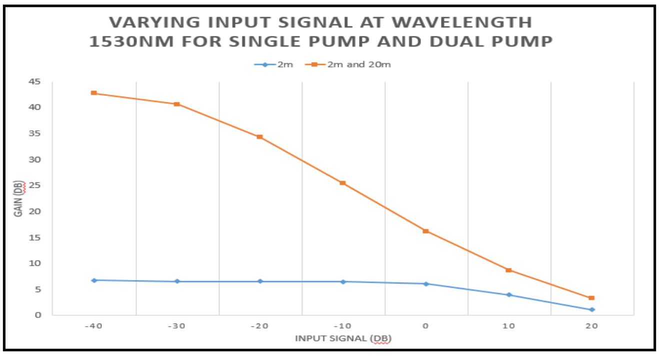


Figure 11: Gain comparison between single and dual stage EDFA by varying the input signal

IV. Conclusion

In conclusion, the gain performance of the dual stage amplifier delivers better performance from the aspects of flat-gain and wideband amplification compared to the single stage amplifier by varying variables such as length of the gain medium, pump power, and input signal power. The gain is highest when the length of the gain medium is 3.5 m for single stage amplifier and 2 m for EDF1 and 20 m for EDF2 for dual stage amplifier. Apart from that, the highest pump power of 700 mW gives the best gain amplification. In short, gain performance is strongly dependent on the length of the gain medium, pump power, and input signal power.

Acknowledgment

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