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Comparative Analysis of Various Optimization Methodologies for WDM System using OptiSystem

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Abstract: A wavelength division multiplexing (WDM) network are widely used in modern telecommunication infrastructure, which are expected to support a large variety of services with different requirements in terms of latency, bandwidth, reliability and many other features. The gain flatness of Erbium Doped Fiber Amplifier (EDFA) plays an important role in WDM network. The main drawback of EDFA is its unequal gain spectrum. The purpose of this project is to investigate different gain flatness techniques for EDFA in order to optimize the WDM performance, as well as to achieve a given bit error rate (BER), gain flatness and noise figure of EDFA through optimized fiber length and pump power. A commercial software, known as 'Optisystem' is used in this project for implementing the physical model of WDM system with different gain flatness techniques. At the end, the results obtained from the simulation of WDM systems implemented with different gain flatness techniques are compared with each other.

Keywords: Erbium-doped fiber amplifier; Fiber length; Pump power; Gain flattening; Noise figure

I. INTRODUCTION

Wavelength Division Multiplexing (WDM) is a highly useful technology in the modern fiber-optic communications. It allows a number of optical carrier signals with different wavelengths to be multiplexed onto a single fiber optic cable. In the following WDM system, (Figure 1) different wavelengths of lights are being multiplexed by a multiplexer in the transmitting end, whereas these wavelengths are again get separated by using demultiplexer in its receiving end. Therefore, a number of channels are simultaneously being transmitted from transmitter to receiver in a Wavelength Division Multiplexing (WDM) system. Optical amplifier is used in between transmitter and receiver, which amplifies the weak optical signals at an optical domain [1].

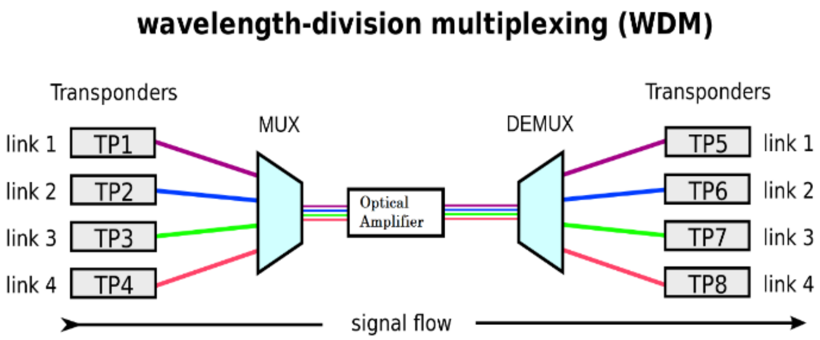

Figure 1: Basic block-diagram of a typical WDM system.

Optical Amplifier is such a device which can directly amplify optical signal without the need to first converting into electrical signal. While an optical signal is being transmitted over a fiber cable, the strength of the signal gets weak

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over a certain distance. In order to further amplify the strength of that optical signal, an optical amplifier is used, which can amplify the optical signal directly in the optical domain. There are different types of optical amplifiers, for example – Erbium Doped Fiber Amplifier (EDFA), Raman Amplifier, Semiconductor Optical Amplifier (SOA) etc. [2].

Among all of them, EDFA is the most common type of optical amplifier, since it has number of advantages, for example - minimum polarization sensitivity, efficient pumping, low insertion loss, high output power, low noise, low distortion, low inter-channel crosstalk and so on. However, the main drawbacks of EDFA are, it cannot amplify all the wavelengths equally. In a long-distance optical transmission system where the optical signal propagates through a number of cascaded EDFAs, the wavelength depended gain spectrum grows an accumulated imbalance in both received optical power as well as signal-to-noise ratio (SNR). This imbalance can limit the performance of WDM system in three different ways. First, the received optical power imbalance can eventually exceed that allowed by the dynamic range of receiver. Second, the accumulated SNR imbalance can result in bit error rate (BER), at certain wavelengths, falling below required levels. Third, the minimum received signal power can fall below what is required by receiver sensitivity for a given bit rate, due to inadequate gain compensation. In this paper, different methodologies for gain flatness are investigated and compared [3].

II. METHODOLOGIES

EDFA gain-flatness are investigated in the following three methodologies - i) optimizing the EDFA length and EDFA pump power, ii) introducing gain flattening filter (GFF), iii) introducing Hybrid Optical Amplifier.

Mobile Ad Hoc Networks (MANETs) consists of a collection of mobile nodes which are not bounded in any infrastructure.

2.1 Gain Flatness by Optimizing the EDFA Length and EDFA Pump Power

In this method, an efficient 16-channels WDM system is designed and simulated using 'Optisystem' software, as shown in Figure 2, in order to achieve the gain flatness by the optimized EDFA length and the optimized pump power of EDFA. This system is modelled in such a way that the gain for the all the WDM channels are flattened within 19 ± 0.24 dB from 1546 nm to1558 nm Band in the optical wavelength spectrum, with the Noise Figure (NF) less than 7 dB and Bit Error Rate (BER) less than 10-18, while transmitting optical pulse at a speed of 10 Gbps [4].

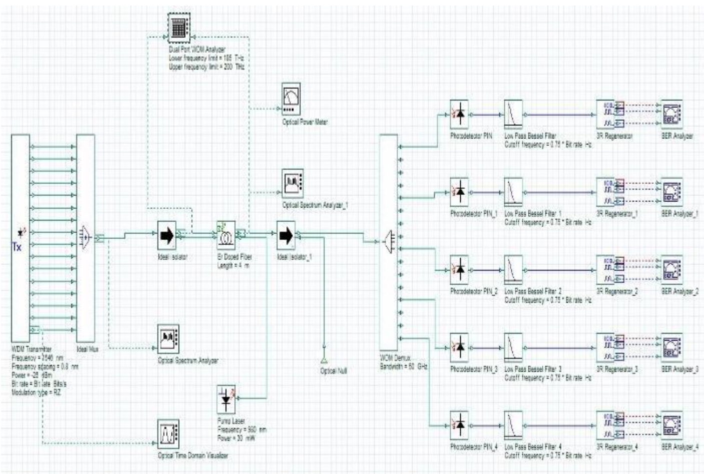

Figure 2: Schematic design of 16-channel WDM system for EDFA Length and pump power optimization.

The schematic in Figure 2 is simulated number of times by varying the EDFA length in between 2 m to 30 m and Pump Power in between 10 m to 80 m with certain intervals. Based on that, it is found that the optimum length of EDFA lies in the range of 4 m to 4.5 m. Therefore, the EDFA length is kept fixed at 4m in this particular experiment.

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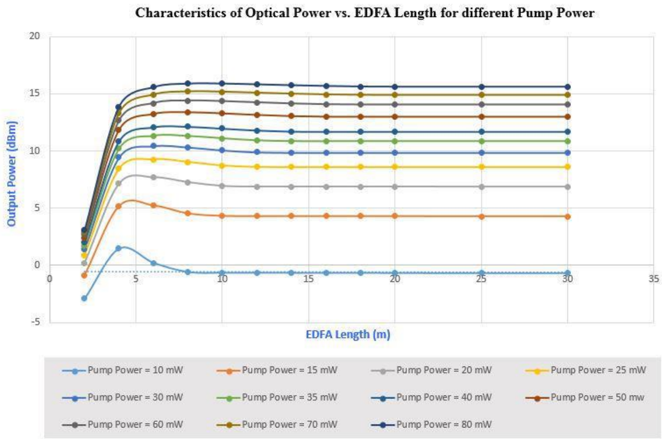

Figure 3: Characteristics of output optical power vs. EDFA length for different pump power.

After optimizing EDFA length, the EDFA gain spectrum is observed from Dual Port WDM Analyzer, at different pump power, in order to introduce the gain flatness (Figure 3).

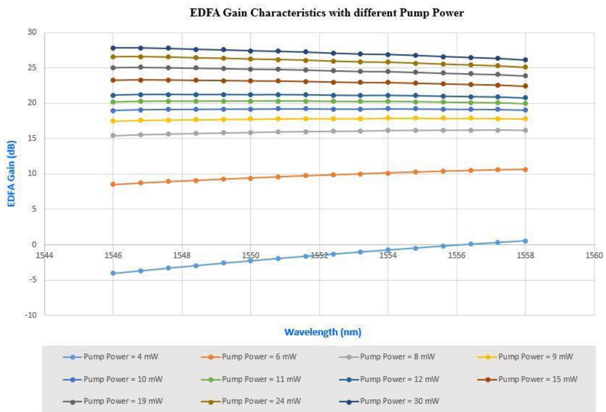

Figure 4: Gain variation of -26 dB/channel amplification for various pump power of EDFA.

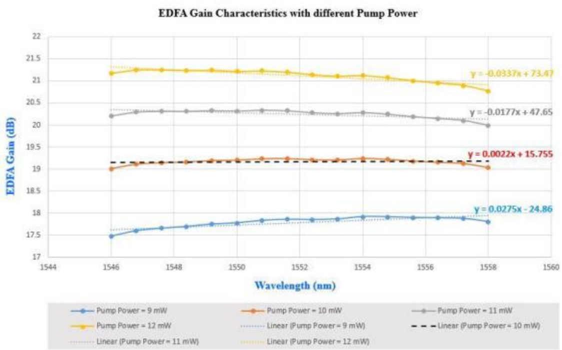

Figure 5: Slope of the EDFA gain characteristics with different pump powers.

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From Figure 4, it is found that, the EDFA gain is almost constant (or flat) for all the wavelengths while the EDFA pump power is around 10 mW. However, for better confirmation of EDFA optical pump power, the slope of the gain curves for near 10 mW pump powers are found, as shown in Figure 5. It is observed that while the EDFA pump power is 10 mW, the slope is minimum (slope=0.0022), which means the EDFA gain for all the wavelengths are almost same. Therefore, it can be concluded that the optimal pump power for EDFA is 10 mW. The following spectrum of noise figure (NF) is observed at different pump power (Figure 6).

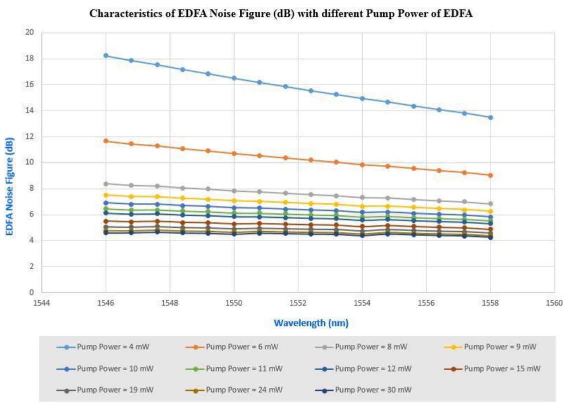

Figure 6: EDFA noise figure (NF) characteristics with various pump powers.

The EDFA pump power of 10 mW offers the acceptable noise figure (NF) of around 6 dB.

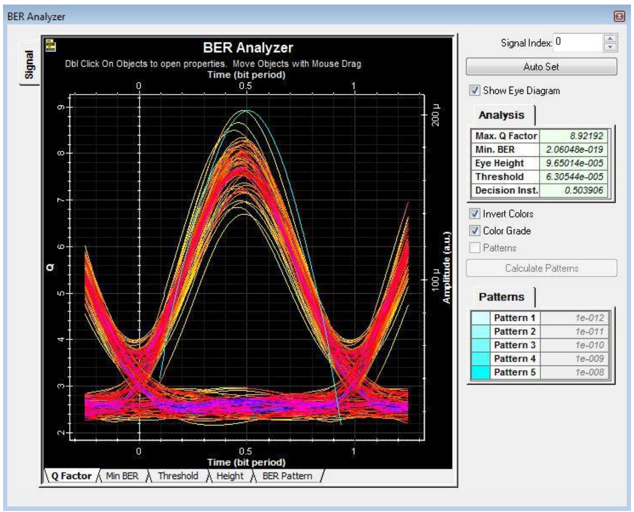

Figure 7: Eye pattern for channel -1.

The big opening of the eye patterns indicates that the inter-symbol-interference (ISI) is minimum, [5]. The width of the opening indicates the time over which the sampling for the detection is performed. The optimum sampling time corresponding to the maximum eye openings yield the greatest protection against noise (Figure 7).

It is found that, as the EDFA pump power increasing, the bit error rate (BER) for the WDM channels is decreasing exponentially. The characteristics of bit error rate (BER) with respect to EDFA pump power are plotted on logarithmic scale, as shown in Figure 8.

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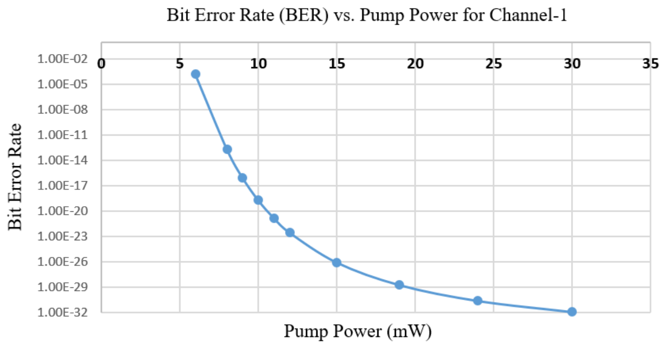

Figure 8: Characteristics of Bit Error Rate (BER) w.r.t EDFA pump power for channel-1.

However, it is also found that, as the optical fiber length increases, the bit error rate (BER) increases exponentially, as shown in Figure 9.

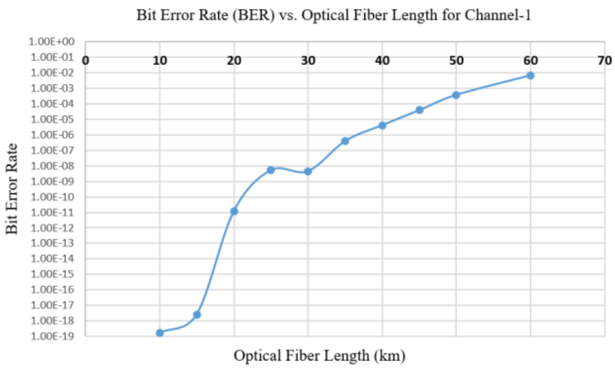

Figure 9: Characteristics of Bit Error Rate (BER) w.r.t optical fiber length for channel-1.

2.2 Gain Flatness by Introducing Gain Flattening Filter (GFF)

The 16-channels WDM system shown in Figure 2 is remodelled into Figure 10, by introducing a gain flattening filter (GFF) in order to overcome the drawback of uneven gain flatness of EDFA [6].

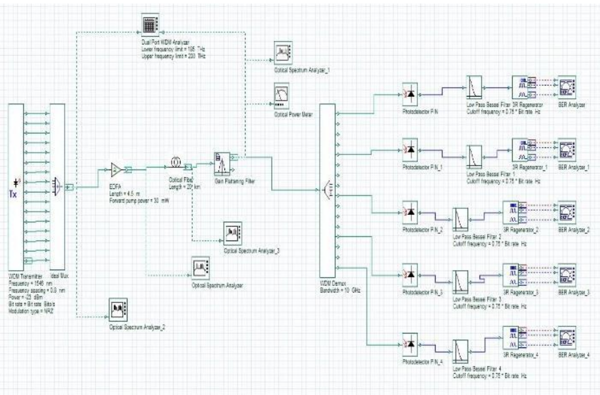

Figure 10: Schematic design of 16-channel WDM system, with introduction of Gain Flattening Filter (GFF).

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The gain flattening filter (GFF) restores all the wavelengths transmitted through WDM system to approximately same intensity. In this approach, the optical gain is almost flat at 19.07 dB and the noise figure (NF) is less than 3.5 dB along with bit error rate (BER) less than 10-18. It is previously found that, the optimum pump power for EDFA is 10 mW. But in this particular experiment shown in Figure 10, intentionally a 30 mW pump power is applied to EDFA, so that the optical gain at the output of EDFA would not be equal for all the wavelengths. Here, the idea is to make the gain flat for all the wavelengths in the later stage by using gain flattening filter (GFF). At the output terminal of the gain flattening filter (GFF), the gain characteristic is expected to be flat. Before optimizing the system shown in Figure 10, the optical power spectrum is found not equal, as expected [7].

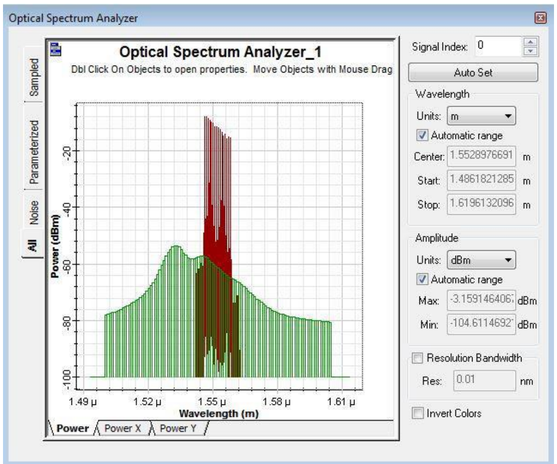

Figure 11: Unequal optical power spectrum (before optimization).

In order to optimize this system, the GFF optimization parameters are modified. The maximum transmission values are kept equal with the maximum output optical signal (Figure 11).

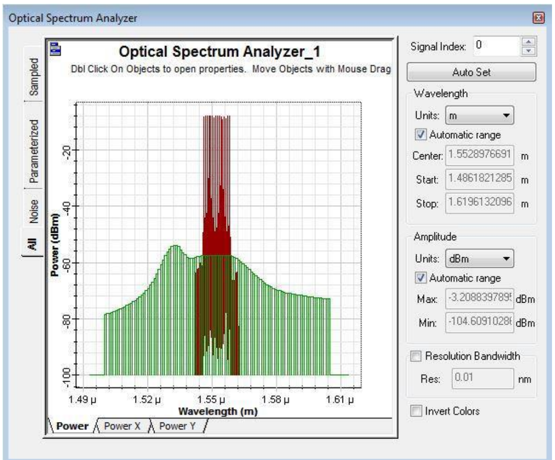

Figure 12: Flat output optical power spectrum (after GFF optimization).

After optimizing the GFF in the system shown in Figure 10, the gain for all the channels are fixed almost at 19 dB as shown in Figures 12 and 13.

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Dual Port WDM Analyzer

Frequency (THz)	Gain (dB)	Noise Figure (dB)
192.42135	19.070182	3.4175705
192.5202	19.070528	3.5306903
192.61916	19.070537	3.4793706
192.71822	19.070535	3.473037
192.81738	19.070532	3.4960938
192.91664	19.070541	3.4938617
193.016	19.070523	3.5118467
193.11547	19.070529	3.487161
193.21504	19.07051	3.4829023
193.31471	19.070535	3.4752698
193.41449	19.070528	3.4730478
193.51437	19.070536	3.5102249
193.61435	19.070527	3.4687262
193.71443	19.07053	3.4991038
193.81462	19.070537	3.4319736
193.91491	19.070361	3.4299159

Analysis | Details

Figure 13: The gain-flatness and noise figure (NF) for different WDM channels, while WDM is optimized with GFF.

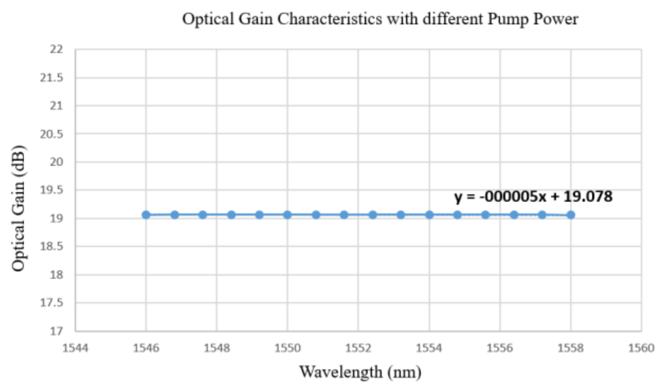

Figure 14: Slope of gain characteristics w.r.t wavelength, while the WDM is optimized with GFF.

The slope for these gain characteristics is found - 0.000005, which is very low. Therefore, the gain is almost equal for all the channels (or wavelengths) transmitted by this WDM system. The noise figure (NF) in this optimized system is approximately 3.4 dB. And the bit error rate (BER) is also very low (Figure 14).

2.3 Gain Flatness by using Hybrid Optical Amplifier (HOA)

Finally, the 16-channels WDM system is again remodeled and this time a Hybrid Optical Amplifier (HOA), consisting of both EDFA and Raman Amplifier are used in order to make the gain spectrum flat for all the wavelengths [2]. This approach exhibits the flat gain for all the WDM channels at approximately 24.44 dB with a noise figure (NF) less than 4.23 dB (Figures 15 and 16).

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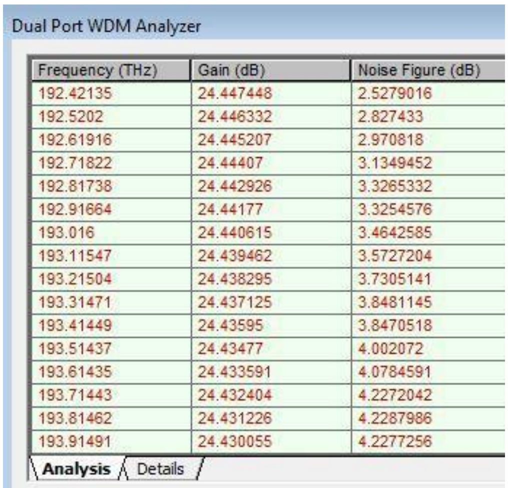

Dual Port WDM Analyzer

Frequency (THz)	Gain (dB)	Noise Figure (dB)
192.42135	24.447448	2.5279016
192.5202	24.446332	2.827433
192.61916	24.445207	2.970818
192.71822	24.44407	3.1349452
192.81738	24.442926	3.3265332
192.91664	24.44177	3.3254576
193.016	24.440615	3.4642585
193.11547	24.439462	3.5727204
193.21504	24.438295	3.7305141
193.31471	24.437125	3.8481145
193.41449	24.43595	3.8470518
193.51437	24.43477	4.002072
193.61435	24.433591	4.0784591
193.71443	24.432404	4.2272042
193.81462	24.431226	4.2287986
193.91491	24.430055	4.2277256

Analysis Details

Figure 15: The gain-flatness and noise figure (NF) for different WDM channels, while WDM system is re-configured with Hybrid Optical Amplifier (HOA).

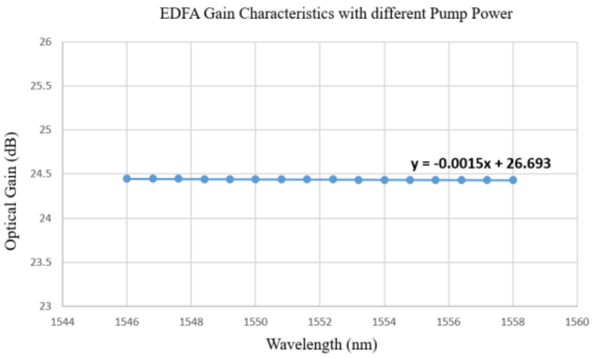

Figure 16: Slope of gain characteristics w.r.t wavelength, while WDM system is re-configured with Hybrid Optical Amplifier (HOA).

The slope of the gain characteristics is - 0.0015.
The noise figure (NF) is also in the acceptable range.

III. COMPARISON AMONG THREE METHODOLOGIES

The advantages and disadvantages of the different approaches for implementing efficient WDM are given in the following table.

Parameter	**Method–1** Gain Flatness by optimizing EDFA length & EDFA pump power	**Method–2** Gain Flatness by introducing Gain Flattening Filter (GFF)	**Method–3** Gain Flatness by using Hybrid Optical Amplifier (HOA)
Optical Gain	19 dB at 10 mW pump power	19 dB	24 dB
Gain Flatness	Comparatively poor result:	Best result out of 3	Intermediate result:

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	Gain spectrum has a slope of 0.0022 dB/nm, gain fluctuation ~ 0.3 dB	methods: Small slope of the gain spectrum -0.000005 dB/nm, fluctuations are negligible	Slope of the gain spectrum is 0.0015 dB/nm, gain fluctuation are negligible
Noise Figure (NF)	~ 6 dB at 10 mW pump power	3.4 dB at 30 mW pump power	3.5 dB In this case, four counter pumps with powers of 550 mW @ 1450, 1452, 1454 & 1456 nm
Bit Error Rate (BER)	Minimum BER: Channel 1: 2.06E-19, at 10 mW pump power	Intermediate BER: Channel 1: 7.54 E-14 at 10 mW pump power	Maximum BER: Channel 1: 6.08E-10 at 10 mW EDFA pump power

Table 1: Advantages and disadvantages of the different approaches for implementing efficient WDM.

According to this above Table 1, the gain achieved from both Method-1 as well as Method-2 are almost equal, whereas the gain achieved by Method-3 is comparatively larger. The noise figure is maximum for Method-1, whereas it is almost equal in both Method-2 and Method-3. The maximum gain flatness is achieved, if the WDM system is implemented using Method-2. That means, if the Gain Flattening Filter (GFF) is introduced in the WDM system, then maximum gain flatness can be obtained. However, the bit error rate (BER) is minimum while WDM system is implemented using Method-1, whereas it is maximum while it is implemented using Method-3.

IV. CONCLUSION

It is concluded that, EDFA exhibits the maximum optical gain, while its length lies in the range of 4 m to 4.5 m. The bit error rate (BER) increases with the increase of fiber length. It is also found that, the different approaches for introducing the flatness of EDFA gain spectrum has some advantages as well as disadvantages. It is also found from the Method-1 that, in an EDFA with a length of 4m, while the pump power is 10 mW, then the optical gain for all the wavelengths are approximately equal to 19 dB. That means, the EDFA gain spectrum is almost flat with this particular configuration. However, the problem with this design approach is, it introduces higher noise figure (NF), which is approximately 6.5 dB. The method-2, where Gain Flattening Filter (GFF) is introduced, also exhibits approximately equal gain as that of method-1, but it gives much better gain-flatness along with the significantly lower noise figure (NF) as compared to that of method-1. However, compared to method-1, this particular design approach exhibits comparatively higher bit error rate (BER). While the design is made using Method-3, the maximum gain is achieved. The noise figure is approximately equal to that of method-2. But the gain-flatness is unfortunately lower compared to that of method-2. Also, the bit error rate (BER) is found maximum in this design approach. It is, therefore, concluded that, the convenient design approach for implementing an efficient WDM system depends on application specific requirements.

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