Comparison of Multiple Optical Amplifier Combinations for a WDM-PDM based Radio over Fiber Systems

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Abstract: An optical system offers great merits over wired electrical transmission media. Yet with its advantages it suffers from the demerit of attenuation of optical signal along the channel similar to a coaxial cable. To counter the effects of attenuation in optical fiber, amplifiers are required along the transmission channel which are called as optical amplifiers which can significantly further improve the performance of an optical system. In this study, a radio over Fiber communication system is designed using multiple combination of optical amplifiers. Further a comparison is made between different combination of the employed optical amplifiers. The amplifiers are compared based on different performance parameters such as bit error rate (BER), Q factor and eye diagram. The optical system is modelled and analysed in Opti system software which is tailor made for optical systems.

Keywords: Bit error rate (BER), Erbium Doped Fiber Amplifier (EDFA), Eye diagram, Polarization Division Multiplexing (PDM), Radio over fiber (RoF) systems, Semiconductor Optical Amplifier (SOA), Signal to noise ratio (SNR), Raman Amplifier, Wavelength Division Multiplexing (WDM).

1. Introduction

Optical amplifiers are essential components of any optical transmission system. Optical amplifiers fulfil the essential need for boosting a weakened incoming optical signal. Optical amplifiers have advantage over earlier amplifiers as the light signal can be amplified directly without the need for first converting the signal into electrical form first [1]. There are three main configurations for connecting optical amplifiers along the channel which are booster amplifier configuration, inline amplifier configuration and preamplifier configuration [2]. In booster amplifier configuration, the optical signal is amplified just before being fed to the optical fiber cable for transmission [2]. In inline amplifier configuration, an optical amplifier is connected between two stretches of optical fiber cables to provide amplification along the channel and restore optical signal to its original level. In preamplifier configuration, optical amplifiers are connected at the receiver to boost the incoming light signal [2].

The three major types of optical amplifiers are Erbium Doped Fiber Ampifiers (EDFA), Semiconductor Optical Amplifier (SOA) and Raman amplifiers. While EDFA and SOA work on the principle of stimulated emission, Raman amplifiers work on Stimulated Raman Scattering (SBS) [3 ,4]. Unlike SOA and Raman amplifiers, EDFAs work in C and L optical bands only [5]. In EDFA, a section of fiber is doped with erbium ions which are at higher energy level and when weak optical signal passes through the fiber the signal interacts with erbium ions and a photon is released at same wavelength as the incoming signal [5 ,6]. Thus, the signal gets amplified using EDFA amplifiers. SOA works on same principle as EDFA. Stimulated emission is caused in an SOA by the presence of quantum dots or quantum wells which contains electrons at higher energy level which causes incoming optical signal to amplify as the electrons interacts with incoming signal and drop to lower energy level and release photon in the process [7]. In Raman amplifiers a higher frequency pump laser with higher energy is used which transfers its energy to the lower frequency incoming light signal using the principle of Stimulated Raman Scattering [8 ,9].

An optical system can further be extended to transmit radio frequency (RF) signals. This system which combines RF with optical system is known as Radio over fiber (RoF) system [10]. Any optical system can further be improved upon by using multiplexing. Wavelength division multiplexing (WDM) and polarization division multiplexing (PDM) can be applied to optical systems to increase bit rate and improve the overall transmission capacity of the system. WDM involves transmitting of multiple signals through optical fiber but at different wavelengths. Similarly, PDM is another multiplexing technique where input signals are transmitted at two different states of polarization which have a ninety-degree phase shift [11].

2. System Description

A four channel Radio over Fiber optical system is designed in this study using Opti system software. The system's performance is enhanced by employing multiple multiplexing techniques such as WDM and PDM and incorporating a combination of optical amplifier to reduce the effect of attenuation on the optical signal along the transmission channel.

The transmitter section is shown in Figure 1. The transmitter is a quad channel, and each channel includes a 10Gbps pseudo-random bit generator that generates the input bit sequence. This sequence is then encoded into a non-return-to-zero (NRZ) format using an NRZ pulse generator. The encoded signal is subsequently modulated by a Mach-Zehnder (MZ) modulator, which uses a continuous-wave (CW) laser to imprint the signal onto an optical carrier. The laser sources operate within a wavelength range of 1550 nm to 1551.5 nm, with 0.5 nm spacing between them for EDFA and Raman amplifiers. For analysis of SOA amplifier, the wavelength of operation taken are 1350nm, 1350.5 nm, 1351 nm and 1351.5nm. The signals from the first two channels are combined using a 2x1 wavelength division multiplexing (WDM) multiplexer, while another 2x1 WDM multiplexer processes the remaining two channels. These multiplexed outputs then pass through polarization controllers, which adjust the azimuth parameter to create two orthogonal signals. Finally, the outputs from both polarization controllers are merged using another 2x1 WDM multiplexer before being transmitted.

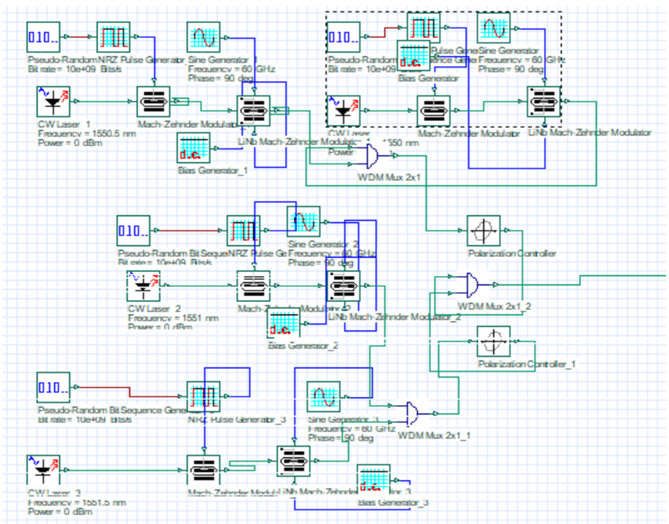

Figure 1: Transmitter section.

The channel consists of an optical fiber of varying length from 15 Km to 60 Km. Further the channel consists of a booster amplifier and a preamplifier. The channel is shown in Figure 2 with EDFA amplifier as booster amplifier and preamplifier. Figure 3 shows channel with EDFA amplifier as booster amplifier and SOA as preamplifier. Figure 4 shows channel with EDFA amplifier as booster amplifier and Raman amplifier as preamplifier.

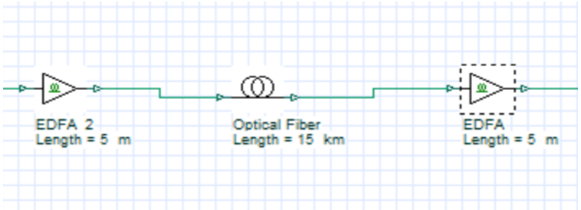

Figure 2: The Channel with EDFA as booster amplifier and a second EDFA amplifier as preamplifier.

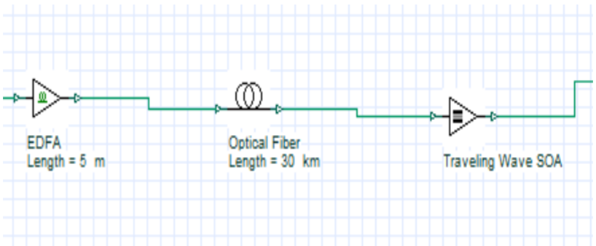

Figure 3: The Channel with EDFA as booster amplifier and SOA as preamplifier.

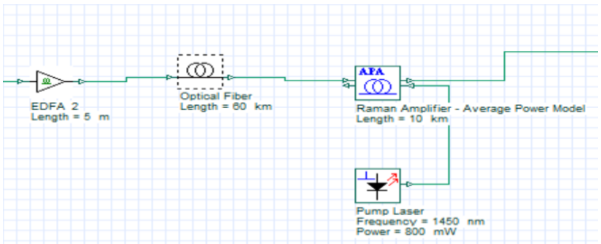

Figure 4: The Channel with EDFA as booster amplifier and Raman amplifier as preamplifier

At receiver, a polarization splitter first separates the received signal based on its state of polarization. The separated signals are then demultiplexed using two 1x2 WDM demultiplexers, which extracts the individual optical channels. The output signal is then refined by passing it through a Gaussian optical filter. Next, a PIN photodiode detects the optical signals and converts them into electrical signals for each channel. Finally, a bit error rate (BER) analyser evaluates the quality of the received signal. The receiver section is shown in Figure 5.

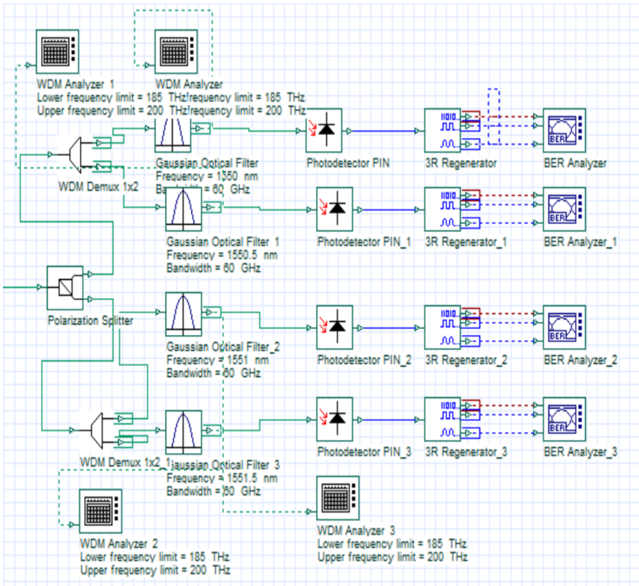

Figure 5: The receiver section.

3. Results and Discussions

Here, comparison between different combination of amplifiers is made by observing a few performance parameters such as OSNR, received input power, Q factor, bit error rate (BER) and eye diagram.

The variation of received power, OSNR, BER and Q-factor for the received optical signal can be viewed in Table 1 when EDFA amplifier is used as booster amplifier and preamplifier as well.

Fiber length	Channel	Received Power(dBm)	Optical Signal to noise ratio(dbm)	BER	Q-factor
15 Km	1550 nm	11.95	40.29	2.27×10^{-54}	15.46
	1550.5 nm	13.26	41.60	6.58×10^{-53}	15.24
	1551 nm	12.38	40.42	2.15×10^{-48}	14.54

	1551.5 nm	13.62	41.66	1.13×10^{-51}	15.05
30 Km	1550 nm	11.30	40.29	8.46×10^{-52}	15.08
	1550.5 nm	12.57	41.56	2.05×10^{-63}	16.75
	1551 nm	11.68	40.41	4.06×10^{-44}	13.86
	1551.5 nm	12.89	41.63	1.97×10^{-47}	14.40
45 Km	1550 nm	10.92	40.28	4.41×10^{-41}	13.36
	1550.5 nm	12.17	41.52	3.30×10^{-49}	14.68
	1551 nm	11.26	40.40	4.23×10^{-33}	11.91
	1551.5 nm	12.45	41.59	1.04×10^{-42}	13.63
60 Km	1550 nm	10.71	40.25	2.06×10^{-29}	11.18
	1550.5 nm	11.93	41.46	1.73×10^{-24}	10.12
	1551 nm	11.00	40.37	6.24×10^{-20}	9.04
	1551.5 nm	12.16	41.54	1.09×10^{-29}	11.24

Table1: Variation for Received power, SNR, BER and Q- factor with distance for EDFA-EDFA based RoF system.

It can be seen from table 1 that at a distance of 15 Km the system shows robust performance with high BER and Q factor. But as distance is increased from 15 Km to 60 Km It is clearly visible from the table 1 that as the distance of the optical fiber cable used to transmit the light signal between the transmitter and receiver is increased from 15 Km to 60 Km the above said parameter values deteriorate.

The eye diagram in case of when EDFA is used as both pre and post amplifiers is shown in Figure 6 and Figure 7. It can be clearly seen that the eye diagram worsens for 60 Km fiber length when compared to fiber length of 15 Km.

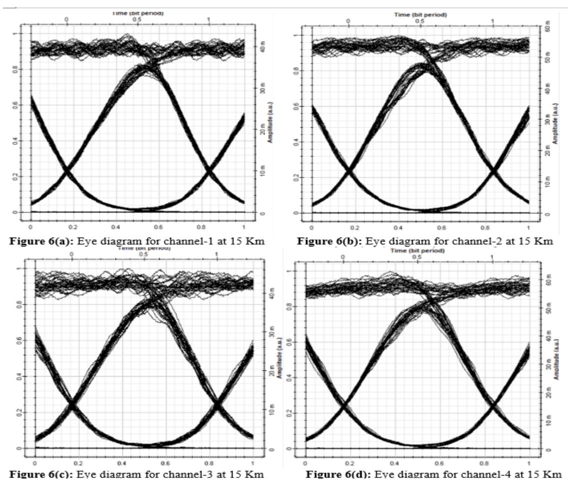

Figure 6: Eye diagram at optical fiber length of 15 Km for EDFA amplifier based optical system

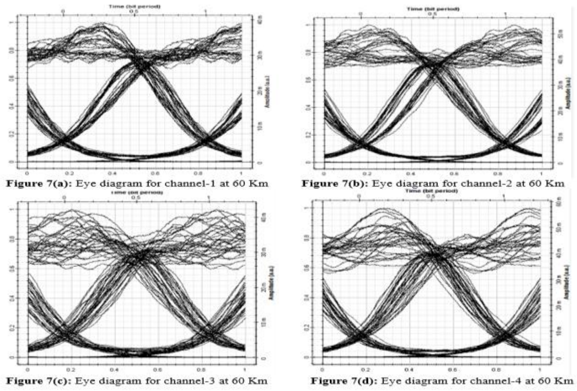

Figure 7: Eye diagram at optical fiber length of 15 Km for EDFA amplifier based optical system.

Next, table 5 shows variation of various performance parameters for EDFA and SOA based RoF system with varying distance. From table 2 it can be observed that again as the distance between transmitter and receiver is increased the performance parameter value decreases.

Fiber length	Channel	Received Power(dBm)	Optical Signal to noise ratio(dbm)	BER	Q-factor
15 Km	1350	-2.20	80.19	1.03×10^{-38}	12.94
	1350.5	-4.23	79.08	1.89×10^{-33}	11.98
	1351	-2.26	80.32	3.26×10^{-40}	13.20
	1351.5	-4.25	79.14	9.82×10^{-35}	12.21
30 Km	1350	-2.31	80.20	2.80×10^{-31}	11.55
	1350.5	-4.35	79.12	1.15×10^{-28}	11.03
	1351	-2.28	80.33	7.18×10^{-33}	11.86
	1351.5	-4.37	79.13	1.53×10^{-26}	10.58
45 Km	1350	-2.40	79.18	7.71×10^{-27}	10.64
	1350.5	-4.44	76.66	1.34×10^{-22}	9.69
	1351	-2.37	80.34	1.39×10^{-24}	10.15
	1351.5	-4.46	79.10	1.06×10^{-22}	9.71
60 Km	1350	-2.48	78.23	7.50×10^{-19}	8.95
	1350.5	-4.50	72.16	5.62×10^{-18}	8.54
	1351	-2.44	78.39	2.86×10^{-20}	9.13
	1351.5	-4.54	76.40	4.38×10^{-18}	8.57

Table 2: Variation for Received power, SNR, BER and Q- factor with distance for EDFA and SOA based RoF system.

The eye diagram for the 15 Km and 60 Km distance for EDFA and SOA based RoF system is shown in Figure 8 and Figure 9.

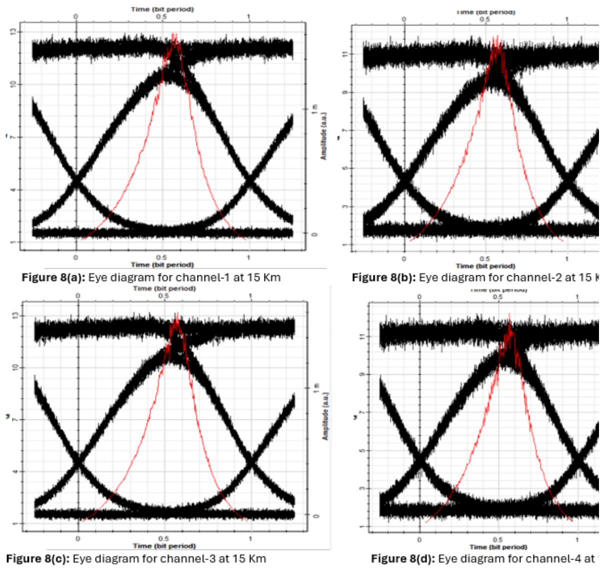

Figure 8: Eye diagram at optical fiber length of 15 Km for EDFA and SOA based RoF system.

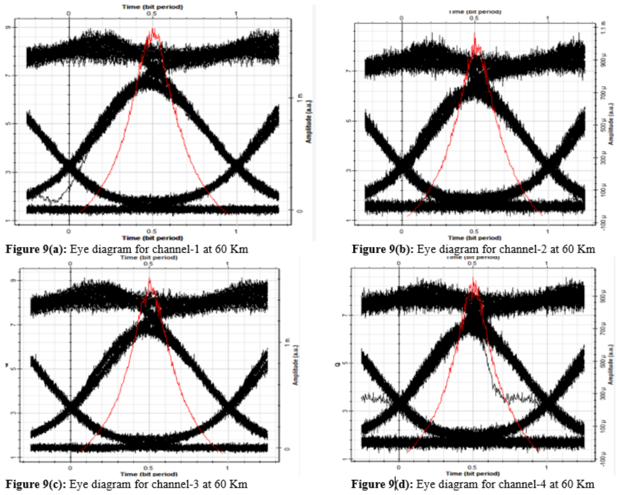

Figure 9: Eye diagram at optical fiber length of 60 Km for EDFA and SOA based RoF system.

Finally, the variation of various parameters for EDFA and Raman amplifier based RoF system is shown in Table 3. The parameters values are observed for all four channels with varying distance from 15 Km to 60 Km.

Fiber length	Channel	Received Power(dBm)	Optical Signal to noise ratio(dbm)	BER	Q-factor
15 Km	1550 nm	15.59	40.41	5.84 x 10^{-54}	15.40
	1550.5 nm	16.72	41.54	5.04 x 10^{-53}	15.25
	1551 nm	15.65	40.53	2.22 x 10^{-48}	14.24
	1551.5 nm	16.70	41.58	1.54 x 10^{-51}	15.03
30 Km	1550 nm	13.50	40.38	1.09 x 10^{-51}	15.06
	1550.5 nm	14.62	41.50	2.34 x 10^{-63}	16.74
	1551 nm	13.55	40.51	3.79 x 10^{-44}	13.87
	1551.5 nm	14.59	41.54	5.05 x 10^{-47}	14.33
45 Km	1550 nm	11.14	40.33	5.33 x 10^{-41}	13.34
	1550.5 nm	12.25	41.43	3.81 x 10^{-49}	14.67
	1551 nm	11.19	40.45	4.45 x 10^{-33}	11.90
	1551.5 nm	12.21	41.48	1.58 x 10^{-42}	13.60
60 Km	1550 nm	8.55	40.23	2.03 x 10^{-29}	11.18
	1550.5 nm	9.65	41.33	1.34 x 10^{-24}	10.15
	1551 nm	8.59	40.35	4.63 x 10^{-20}	9.08
	1551.5 nm	9.61	41.38	8.88 x 10^{-30}	11.26

Table 3: Variation for Received power, SNR, BER and Q- factor with distance for EDFA and Raman amplifier based RoF system.

The eye diagram for EDFA and Raman amplifier based RoF system is shown in figure 8 and Figure 9 for 15 Km and 60 Km distance for all four channels.

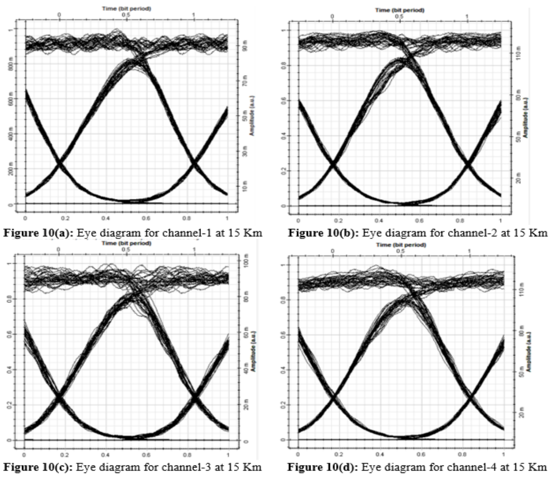

Figure 10: Eye diagram at optical fiber length of 60 Km for EDFA and Raman amplifier based RoF system.

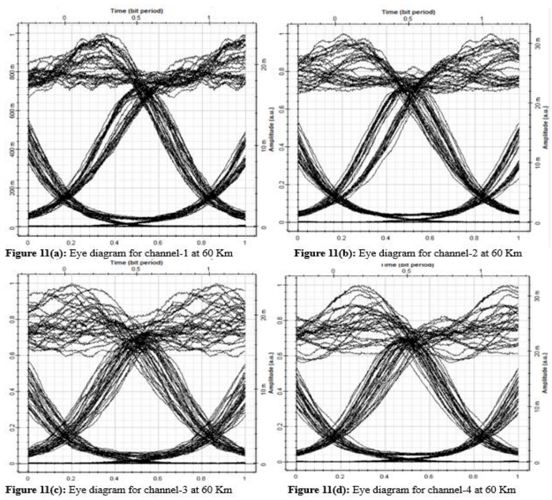

Figure 11: Eye diagram at optical fiber length of 60 Km for EDFA and Raman amplifier based RoF system.

4. Conclusions

Here, combinations of optical amplifier which is used as booster amplifier and preamplifier are compared on the basis of multiple performance parameters such as BER, Q-factor and eye diagram. The optical system considered is a four channel Radio over Fiber system with WDM and PDM multiplexing techniques. For EDFA based

RoF system at 15 Km fiber length, BER and Q factor for channel 1 are 2.27 x 10^{-54} and q factor is 15.46, for channel 2 BER is 6.58 x 10^{-53} and Q factor is 15.24, for channel 3 BER is 2.15 x 10^{-48} and Q factor is 14.54, for channel 4 BER is 1.13 x 10^{-51} and Q factor is 15.05. For EDFA and SOA based RoF system at 15 Km fiber length, for channel 1 BER is 1.03 x 10^{-38} and Q factor is 12.94, for channel 2 BER is 1.89 x 10^{-33} and Q factor is 11.98, for channel 3 BER is 3.26 x 10^{-40} and Q factor is 13.20 and for channel 4 BER is 9.82 x 10-^{35} and Q factor is 12.21. For EDFA and Raman amplifier based optical system at 15 Km fiber length, for channel 1 BER is 5.84 x 10^{-54} and Q factor is 15.40, for channel 2 BER is 5.04 x 10^{-53}, and Q factor is 15.25, for channel 3 BER is 2.22 x 10^{-48} and Q factor is 14.24, for channel 4 BER is 1.54 x 10^{-51} and Q factor is 15.03. As distance increases the performance parameters worsens and detrimental effects of factors such as attenuation and dispersion are visible. The same may be viewed from the eye diagram. But by using amplifiers the signal can be transmitted to longer distances. While EDFA-EDFA based RoF system and EDFA- Raman amplifier based RoF system showed identical results and resilience to attenuation but EDFA- SOA based RoF system, the performance parameters value is worse as compared to other two systems for the transmission parameters considered.

5. References

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