Enhanced Performance Analysis Comparison of Inter – Aircraft Optical Wireless Communication (IaOWC) Link Using Optical Amplifier

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Abstract — *Optical wireless communication (OWC) also known as free space photonics or free space optics is a data transmission technology in which information is transmitted between two points separated by a certain distance is space using optical signals as the information carrier and free space/air as the propagation medium. OWC technology can be deployed to achieve inter-satellite links, inter-aircraft links and terrestrial links. Free space optical (FSO) communication has emerged as a viable technology for broadband wireless applications which offers the potential of high bandwidth capacity over optical wavelengths. We compare different types of amplifiers in order to find the one which is the most efficient and effective with maximum performance over the link distance.*

Keywords — *IaOWC; FSO; EDFA; Raman; SOA; BER; SNR; Total Received Power*

1. INTRODUCTION

Free Space Optical (FSO) communication or Optical wireless communication (OWC) has emerged as a viable technology for next generation broadband wireless applications in different areas of the long and short haul communications space from inter-satellite links to inter-aircraft links and terrestrial links. In order to meet the growing demand for channel capacity, bandwidth, and high data transmission rates due to the increasing usage of multimedia application such as video conferencing, live streaming, and high speed internet etc., mobile communication companies have started looking for an alternative solution to the traditional radio frequency (RF) based communication systems which have a limited amount of licensed spectrum. Optical Wireless Communication (OWC) systems can be considered as an attractive solution to this problem since spectrum licensing is not required for optical carrier signals. FSO offers a great deal of potential for broadband connectivity but variations in temperature and pressure of the atmosphere leads to refractive index variation along the transmission path. OWC is a line-of-sight (LoS) technology which requires a direct line of sight between the transmitter and the receiver units for reliable transmission of information.

The necessary line of sight may get disrupted by clouds and other obstacles in case of IaOWC links. Research has been carried out by different organizations, institutions, and individuals to increase the link reliability of OWC links. Here [1], an improved performance analysis of a 1.25 Gbps IaOWC link consisting of two aircraft at a distance 100 km by deploying EDFA as a pre-amplifier in IaOWC link has been reported. This paper builds upon that and employs different amplifiers that are used and the results are compared to find the best one.

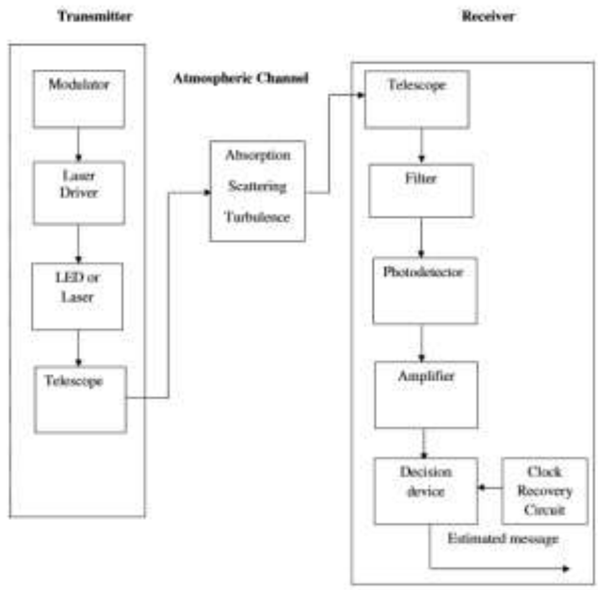

Fig. 1. FSO System

2. SYSTEM DESIGN AND DESCRIPTION

The IaOWC system can be designed using the following equation:

$$P_r = P_t n_r n_t \left(\frac{\lambda}{4\pi Z}\right) G_t G_r L_t L_r \quad (2.1)$$

where, P_r and P_t represent total received and transmitted power level respectively, n_r and n_t represent the optical efficiency of the receiver and transmitter respectively, G_r and G_t represent optical gain of the receiver and transmitter respectively and L_r and L_t represent the pointing losses of the receiver and transmitter respectively. λ represents the wavelength and Z represents the link distance. The optical gain at the receiver and transmitter end is given by the equation:

$$G = \left(\frac{\pi D}{\lambda}\right)^2 \quad (2.2)$$

where, D is the aperture diameter of the antenna.

It can be observed from equation (2.1) that the total received power is directly proportional to the total transmitted power and directly proportional to the gain of the antenna. Therefore, in order to increase the OWC link distance and enhance the link performance we have to either increase the total transmitted power or enhance the gain of the system. The transmission power cannot be increased further because of the harmful effects of high transmission power levels on living beings, therefore the more practical and sensible approach would be to increase the system gain.

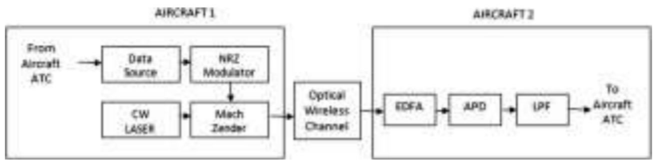

Fig. 2.1. Design of an inter-aircraft optical wireless communication link

Serial Number	Parameter	Value/Type
1.	Operating wavelength (nm)	1550
2.	Bit rate (Gbps)	1.25
3.	Atmospheric attenuation (dB/km)	0.4
4.	Transmission power level (mW)	60
5.	Pointing error (urad)	1
6.	Link distance (km)	100
7.	Additional losses (dB)	1
8.	EDFA length (m)	5
9.	SOA injection current (A)	0.15
10.	Modulation format	NRZ
11.	Aperture diameter (cm)	20

Table 2.1. Simulation Parameters

3. SIMULATION AND RESULTS

An IaOWC system broadly consists of three sections—the transmitter section, the propagation channel and the receiver section. The information from the aircraft air traffic control system (ATC) is directed towards the aircraft transmitter. The transmitter section is further divided into four subsections—Pseudo Random Bit Sequence (PRBS) generator which generates the information in the form of binary data. The binary data from PRBS is directed towards non-return to zero (NRZ) pulse generator which converts the binary data into electrical signals. These electrical signals are modulated with optical carrier signals using Mach–Zender Modulator (MZM) and a continuous wave (CW) laser operating at a central wavelength of 1550 nm. This optical information signal is transmitted into free air/vacuum using the transmitting antenna. At the receiver section, the optical information signal is received by the receiver antenna which is connected to an EDFA amplifier. EDFA amplifies the weak information signal which has been distorted due to atmospheric turbulence and scintillation effects before transmitting it to the photo detector. The Avalanche photo detector (APD) converts the optical signal into an electrical signal. A low pass Bessel filter (LPF) is used to remove any high frequency noise present on the received information signal. The quality of the received signal is analysed by BER tester.

We then have to replace the EDFA optical amplifier used in pre-amplifier mode by other amplifiers such as Raman amplifier and Semiconductor Optical Amplifier (SOA) and obtain and compare the results of SNR vs. link distance (Range) and Total received power vs. link distance (Range).

EDFA Pre-amplifier

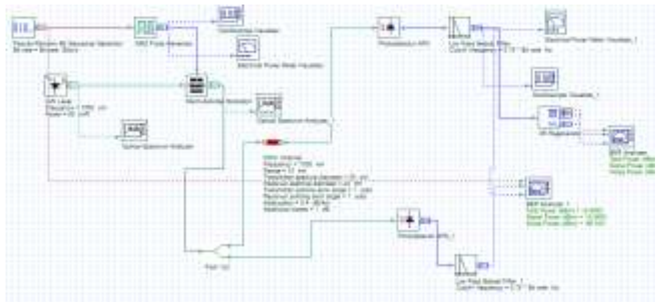

Fig. 3.1. Basic Optical Wireless Communication Schematic without using any optical amplifiers consisting of transmitter section, channel and receiver section

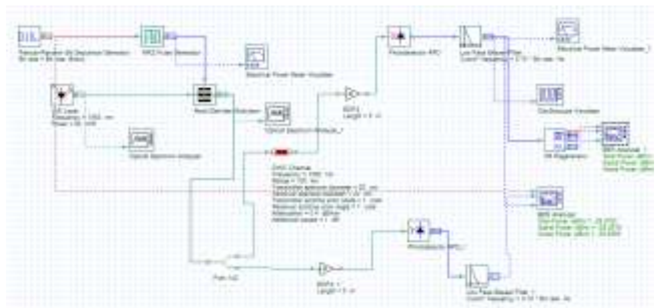

Fig. 3.2. Basic Optical Wireless Communication Schematic with EDFA pre-amplifier

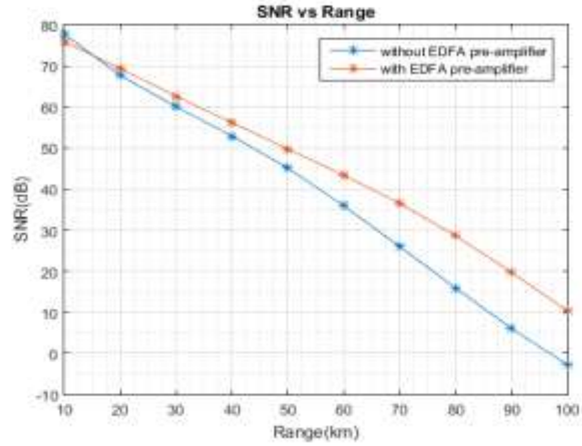

Fig. 3.3. SNR vs. Range plot comparison with and without using EDFA pre-amplifier

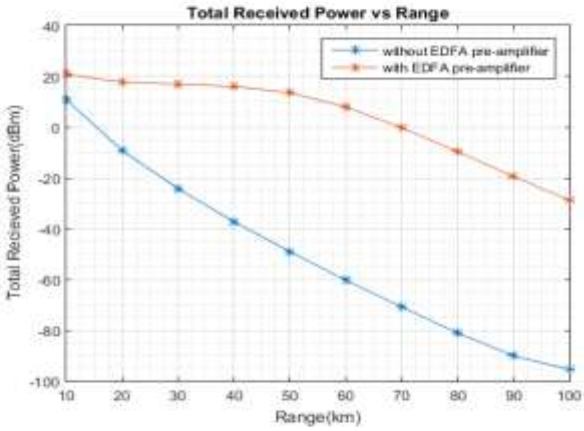

Fig. 3.4. Total received power vs. Range plot comparison with and without using EDFA pre-amplifier

We can now observe that the IaOWC link performance has improved using EDFA pre-amplifier. We have to better this by using other optical amplifiers and comparing the results to know which is the best and most efficient optical amplifier to increase and improve the optical wireless link distance and performance.

Raman Pre-amplifier

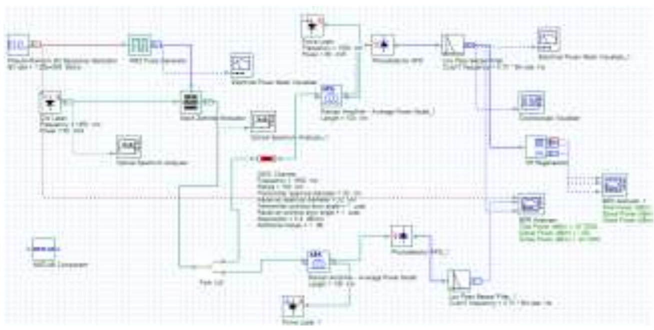

Fig. 3.5. Optical Wireless Communication Schematic with Raman pre-amplifier with a pump laser frequency of 1550nm and power of 60mW

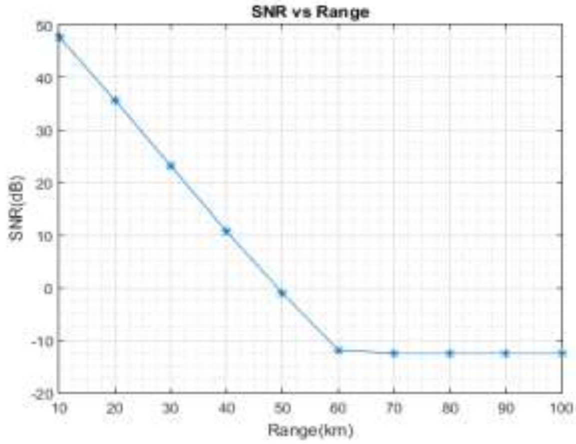

Fig. 3.6. SNR vs. Range plot using Raman pre-amplifier

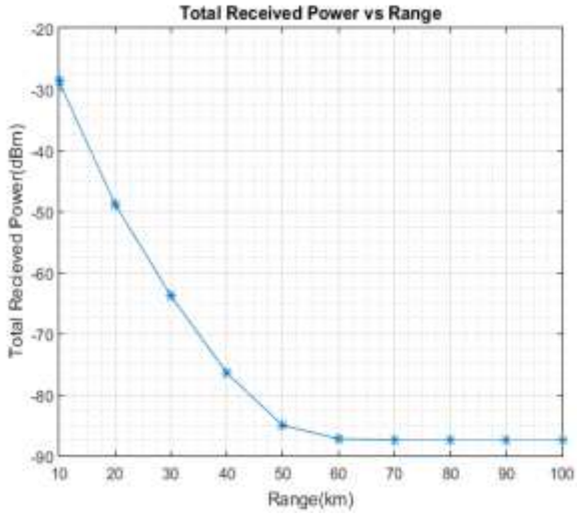

Fig. 3.7. Total received power vs. Range plot using Raman pre-amplifier

SOA (Semiconductor Optical Amplifier) Pre-amplifier

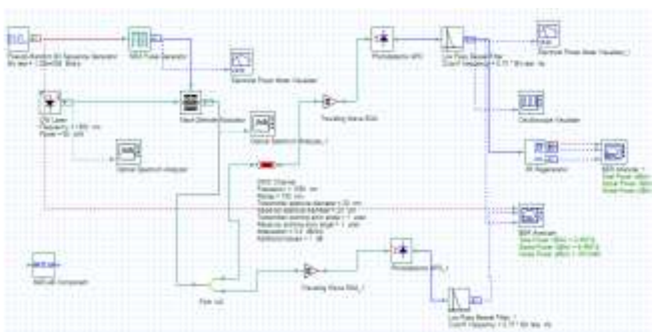

Fig. 3.8. Optical Wireless Communication Schematic with Semiconductor Optical Amplifier (SOA) pre-amplifier with an injection current of 0.15A

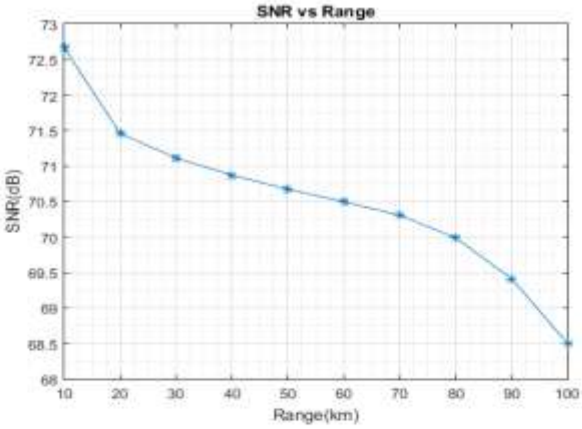

Fig. 3.9. SNR vs. Range plot using SOA pre-amplifier

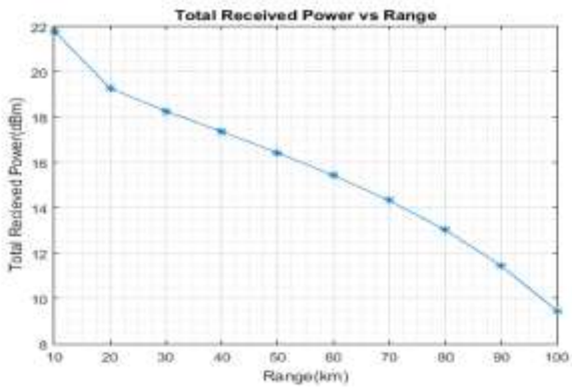

Fig. 3.10. Total received power vs. Range plot using SOA pre-amplifier

We can observe from the above graphs that as the range increases the SNR and total received power decreases for all optical amplifier.

Now we have to compare the performance of the optical wireless link by combining all the above results to know which is the best and most efficient optical amplifier in pre-amplifier mode to increase the range and performance of the optical wireless link.

RANGE(in km)		SNR (dBm)				Total Rcvd. Power (dBm)		
	w/o EDFA	w/ EDFA	Raman	SOA	w/o EDFA	w/ EDFA	Raman	SOA
10	71.7583	75.9261	47.7067	72.6667	10.8403	20.8703	-28.7632	21.8029
20	67.7306	69.3710	35.6788	71.4613	-9.2008	17.7207	-48.7981	19.2881
30	60.0790	62.6427	23.1550	71.1140	-24.2444	17.0189	-63.8156	18.2734
40	52.9561	56.1464	10.6640	70.8717	-37.2416	16.0546	-76.4514	17.3686
50	45.1229	49.8023	-1.0673	70.6720	-49.1167	13.4878	-85.0190	16.4356
60	35.9486	43.3930	-11.8892	70.4986	-60.2784	7.9818	-87.2534	15.4356
70	25.9762	36.5400	-12.4840	70.3065	-70.9315	-0.2436	-87.4846	14.3267
80	15.8983	28.6434	-12.4893	69.9885	-81.1035	-9.7254	-87.5042	13.0336
90	6.0487	19.7303	-12.4922	69.4115	-90.1451	-19.4684	-87.5047	11.4476
100	-2.8364	10.3243	-12.4938	68.4999	-95.5020	-28.8762	-87.5083	9.45518

Table 3.1. SNR (dBm) and Total Received Power (dBm) vs. Range (km)

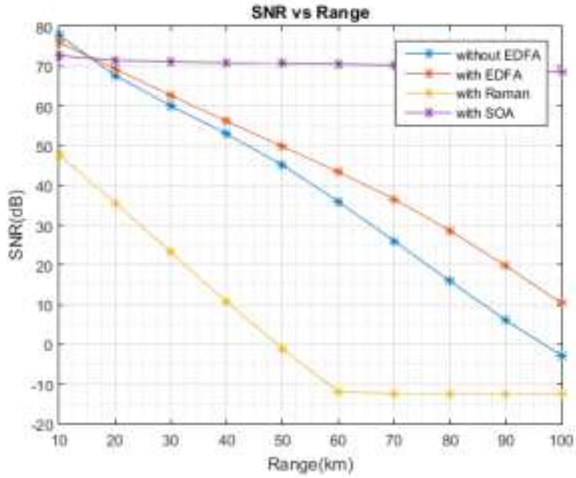

Fig. 3.11. SNR vs. Range plot comparison of different optical amplifiers

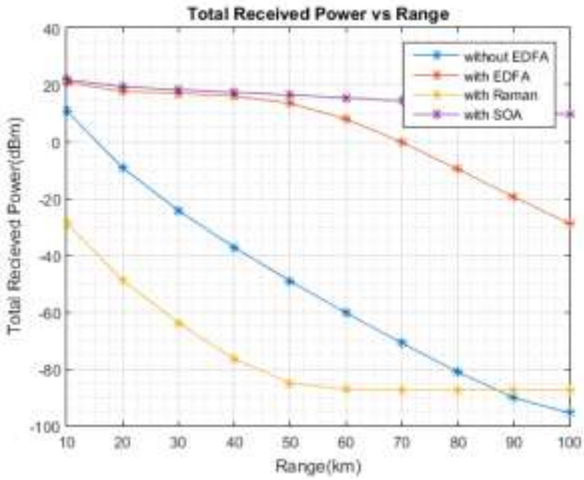

Fig. 3.12. Total Received Power vs. Range plot comparison of different optical amplifiers

We can observe from the graphs and table above that SOA pre-amplifier has a much better SNR and Total received power as compared to other optical amplifiers throughout the link range which is helpful in increasing the link range and performance even further.

Reinforcing this with the help of data from BER testers for the different optical amplifiers at different link distances.

Range (in km)		Bit Error Rate (BER)		
	w/o EDFA	w/ EDFA	Raman	SOA
10	0	0	0	5.03881e-007
20	0	0	0	4.8379e-011
30	0	0	4.17553e-036	2.22716e-011
40	0	0	0.000402684	2.49885e-011
50	0	0	1	2.96043e-011
60	0	0	1	3.4762e-011
70	1.58236e-058	0	1	5.18144e-011
80	1.65139e-007	0	1	1.33828e-010
90	1	3.91032e-138	1	6.59293e-010
100	1	1.6888e-038	1	7.35711e-009

Table 3.2. Bit Error Rate (BER) vs. Range (km)

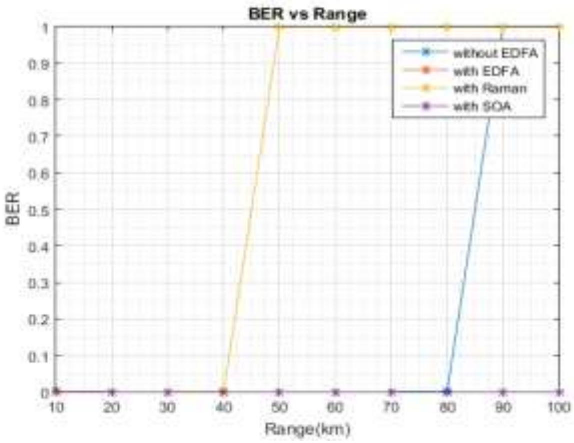

Fig. 3.13. Bit Error Rate (BER) vs. Range plot comparison of different optical amplifiers

We can observe from the above graph and table that the SOA pre-amplifier is the best and most efficient because we are getting acceptable performance of Q-factor ~ 6 and BER <= 10^{-9} in the entire link range using SOA pre-amplifier.

We can also observer from the electrical power meter visualizer on the schematic placed on both the transmitter end and the receiver end that the power loss is much less in SOA as compared to other types of amplifiers for the given link range. SOA pre-amplifier is the winner.

4. CONCLUSION

In this paper, an inter-aircraft optical wireless communication link has been designed and we have analyzed the performance of the FSO link communication system modelled with different optical amplifiers. We have obtained acceptable performance level of Q-factor ~ 6 and BER <= 10^{-9}. We have accomplished and generated the respective results.

It can be seen from the tests performed above and the graphs obtained that SOA is the most efficient amplifier when it comes to long distance optical wireless communication providing better SNR values and Total Received Power as compared to other types of amplifiers. It is an economic, easy to set up, high performance solution for long haul WDM networks in any establishment. Hence, by deploying SOA in an optical wireless communication link, the performance of the system can be enhanced and the link distance and link performance can be increased.

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