RESEARCH ARTICLE OPEN ACCESS

Review Paper: Hybrid Amplifiers in FSO System

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Abstract:

Free Space Optics is a medium with high bandwidth which has maximum data rate. Demand for large data speed capacity has been increasing exponentially due to the massive spread of internet services. So with the growing transmission rate and demand in the field of optical communication, the electronic regeneration has become more expensive. With the introduction of power optical amplifiers the cost of converting optical signals to electronic signals has been brought down immensely. In this paper, different combinations of hybrid amplifiers have been studied and emerged in FSO system. Their performances have been compared on the basis of transmission distance.

Keywords **—FSO, FOC, RZ, AM, FM, PM, SOA, EDFA, RFA, DFA, FPA, DWDM, OSNR.**

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I. INTRODUCTION

There has always been a demand for increased transmission capacity of information, and engineers continuously pursue technological routes for achieving this goal. Fiber optics is one of the most important communication media in communication system. Optical fiber has various advantages over existing copper wire in respect of negligible transmission loss, high speed, and high information carrying capacity. The increasing need for high speed data and broad bandwidth communication transmission is driving the development of 100 gigabit per second (Gbps) communication links [1].

II. FSO (FREE SPACE OPTICS)

Free-space optical communication (FSO)uses the same principle and has the same capabilities as that of fiber optics, but at a lower cost, long ranges operation, high security and very fast deployment speed. FSO is a wireless communication technology which utilizes light for the transmission of data through air in the similar manner as the fiber optics uses a fiber cable. Free Space Optics (FSO) works on the principal of laser driven technology which uses light sources and detectors to transmit and receive information, through the atmosphere same as Fiber Optic Communication (FOC) link. The motivation for FSO is to eliminate the effort of installing fiber optic cable, time, cost and yetmaintaining the data rates up to 1Gb/s or for transmission of voice, video and data services. FSO technology transmission is very simple. It is a technology that uses light propagating in free space to transmit data between two stations [2].

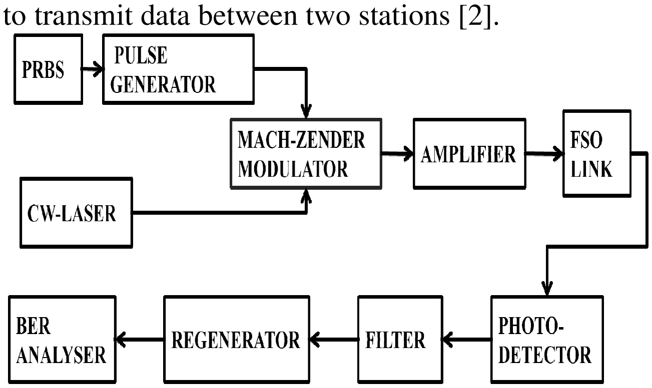

Fig.1 Block Diagram of FSO

As shown in fig.1, the pulse generator generates pulses (information signal) to be transmitted through the FSO link. The Pulse shape can be Triangular wave, Return to Zero/Non-return to zero (RZ/NRZ) pulse, Gaussian pulse, Impulse or M-ary generator. These pulses are further modulated with a carrier which is an optical signal. Optical carrier wave can be produced by using a LASER or LED. Optical modulator can be Mach-Zehnder, Amplitude Modulation (AM), Frequency Modulation (FM) or Phase Modulation (PM). Modulated signal is transmitted on FSO link, then optical demodulator is used to convert optical signal into electrical signal. Free space optics (FSO) communication links have some distinct advantages over conventional microwave and optical fiber communication systems because of their high carrier frequencies, large capacity, enhanced security and high data rate.

FSO is based on connectivity between two stations consisting of optical transceiver to achieve full duplex communication. However,the transmission performance of the free space optics is highly affected by the various atmospheric conditions which cause the degradation of the performance of FSO link.

A. *Atmospheric Turbulence:*

The atmospheric attenuation Att_{atmos} (dB/km) can be written as:

$Att_{atmos} = Att_{clearsky} + Att_{excess}$ ……………. (1)

where$Att_{clearsky}$is specific attenuation under clear sky. Att_{excess} is specific attenuation due to the presence of rain, fog, mist, haze, snow etc [4].

Atmosphere attenuation can be caused by several factors, including absorption of the beam via molecules in the atmosphere and attenuation of the beam due to Rayleigh or Mie scatter with molecules or aerosol particles in the air. For most FSO applications, Mie scatter (especially due to fog) is often dominant. Signal Propagation is effected by snow, fog, clouds and dust particles but major factor of attenuation is rain [3].

B. *Rainfall Attenuation*

Rain is formed by water vapour contained in the atmosphere. It consists of water dropletswhose form and numbers are variable in time and space. Rain attenuation represented by γ_{rain}(dB/km) is defined by given relation [4].

γ_{rain}= k.R^{α} ……………………… (2)

Here R represents rain intensity (mm/hr.) and k and α is rain coefficient which can be taken according to ITU recommendations as:

TABLE I

Parameters used for attenuation due to rain

Location	k	α
Japan	1.58	0.63
France	1.076	0.67

C. *Fog Attenuation*

Fog is the most detrimental factor among the entire attenuation factor. It can be described as a cloud of small particles of water, smoke, ice or a combination of these near the earth's surface thereby scattering the incident light and hence reducing the visibility. Attenuation of the optical signal at a distance R, due to fog [5] is determined by the Beer-Lambert law given as

Att_{fog}=$e^{\alpha(fog)}$R …………………… (3)

Here α(fog) is the attenuation coefficient, given by

$\alpha(fog)$=$\frac{10logV}{V(km)}\left(\frac{\lambda}{\lambda_0}\right)^{-q}$……………… (4)

Here V (km) stands for visibility, λ stands for wavelength and λ_0 as visibility wavelength reference (550 nm) and q is the size distribution coefficient of scattering.

q can be obtaining by utilizing the Kim or Kruse models.

For Kruse model q is given as,

$$q = \begin{cases} 1.6 & \text{if } V > 50km; \\ 1.3 & \text{if } 6km < V < 50km; \\ 0.585\ V^{\frac{1}{3}} & \text{if } V < 6km. \end{cases}$$ ……. (5)

For Kim model q is given as,

$$q = \begin{cases} 1.6 & \text{if } V > 50km; \\ 1.3 & \text{if } 6km < V < 50km; \\ 0.16V + 0.34 & \text{if } 1km < V < 6km; \\ V - 0.5 & \text{if } 0.5km < V < 1km; \\ 0 & \text{if } V < 0.5km \end{cases}$$ ….. (6)

Kruse model states less attenuation for higher wavelengths but Kim rejected such wavelength dependent attenuation for low visibility in dense fog [5].

D. *Snow Attenuation*

Specific attenuation γ_{snow}(dB/km) due to snow as a function of snowfall rate is given by the following relation [4].

$$\gamma_{snow} = \alpha . S^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where S is snowfall rate (mm/h) and α, b (functions of wavelength λ(nm)) which can be taken according to ITU recommendations as:

Table II
Value of snow attenuation parameters α and b

Type of Snow	α	b
Wet Snow	0.0001023λ + 3.785	0.72
Dry Snow	0.0000542λ + 5.495	1.38

E. *Scintillation Loss*

Atmospheric turbulence causes due to the variation in temperature and pressure which further causesscintillations [6]. When the beam is scintillated, photons of light are temporally steered by pockets of air in random direction. The received signal level at the detector fluctuates due to thermally induced changes in the index of refraction of the air along the transmit path. For the case of free-space optics, this implies horizontal path propagation and therefore stronger scintillation [7]. To overcome the scintillation effects automatic gain control mechanism is used and also clock recovery phase lock loop time constant eliminates the effects of scintillation and jitter transference [8].

The system capacity and transmission distance of free space optical communication link area affected by atmospheric turbulence, which occurs because of random fluctuations in the refractive index of air. To reduce the effect of scintillation in FSO channels, optical amplifiers are used which also reduces the intensity of fluctuations and amplify the optical signal.

III. OPTICAL AMPLIFIERS:

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal.This device works on the principle of stimulated emission.Stimulated emission is the process by which an incoming photon of a specific frequency can interact with an excited atomic electron (or other excited molecular state), causing it to drop to a lower energy level. Light amplification occurs when incident photon and emitted photon are in phase and release two more photons.To achieve optical amplification, the population of upper energy level has to be greater than that of lower energy level and this condition known as population inversion. This can be achieved by exciting electron into higher energy level by external energy source called pumping [9]. There are three ways in which optical amplifier can be used to enhance the performance of data link.

1. A booster amplifier is used to increase the transmitter's output just before the signal enters an optical fiber and the optical signal is attenuated when it travels in optical fiber.
2. An inline amplifier is used to regenerate the optical signal to its optical power level.
3. And an optical pre amplifier is used at the end of the optical fiber link in order to increase the sensitivity of optical receiver.

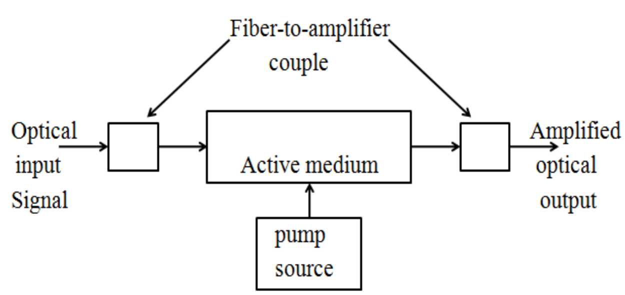

Fig. 2Optical Amplifier

Types of optical amplifier:

The two main Optical amplifier types can be classified as semiconductor optical amplifier (SOAs) and active fiber or doped-fiber amplifiers (DFAs). All amplifiers increase the power level of incident light through a stimulated emission process. The mechanism to create the population inversion that is needed for stimulated emission to occur is the same as is used in laser; it does not have the optical feedback mechanism that is necessary for lasing to take place. Thus an optical amplifier can boost incoming signal level, but it cannot generate a coherent optical output by itself [10].

Amplifier gain

One of the most important parameter of an optical amplifier is the signal gain or amplifier gain which is denoted by G

$$G=\frac{P_{s,out}}{P_{s,in}} \text{.............................} (7)$$

where $P_{s,in}$ and $P_{s,out}$ are the input and output powers, respectively, of the optical signal being amplified [10].

A. Semiconductor optical amplifier (SOA)

SOAs amplify incident light through stimulated emission. An electrical pump current is used to excite the electrons in the active region of the SOA. When the optical signal travels through the active region, it causes these electrons to lose energy in the form of photons and get back to the ground state. The stimulated photons have the same wavelength as the optical signal, thus amplifying the optical signal. The basic working principle of a SOA is the same as a semiconductor laser but without feedback [11]. There are two types of SOAs: Fabry-perot amplifiers (FPA) and non resonant travelling-wave amplifiers. In Fabry-perot amplifiers,when the light enters FPA it gets amplified as it reflects back and forth between the mirrors until emitted at a higher intensity. It is sensitive to temperature and input optical frequency. In non resonant travelling wave amplifiers, it is the same as FPA except that the end facets are either antireflection coated or cleaved at an angle so that internal reflection does not take place and the input signal gets amplified only once during a single pass through the device.They have a large optical bandwidth and low polarization sensitivity [10].

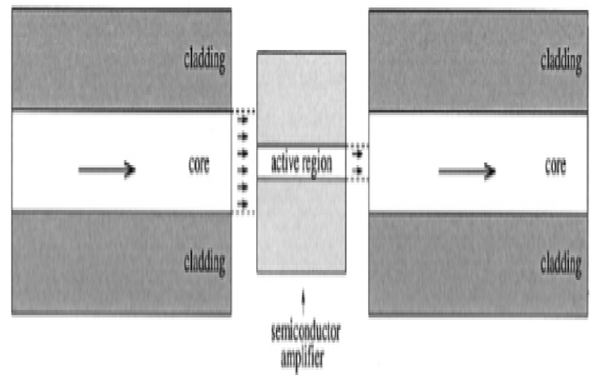

Fig. 3 Block diagram of SOA

B. Erbium-doped fiber amplifier (EDFA)

The most popular material for long-haul telecommunication applications is silica fiber doped with erbium which known as erbium doped fiber amplifier or EDFA. In some cases ytterbium (yb) is added to increase the pumping efficiency and the amplifier gain. The EDFA depends on three parameters: length of erbium doped fiber, pump laser and wavelength selective coupler to combine the signal and pump wavelength. EDFA is capable of amplifying the entire wavelength ranging from 1530 to 1560 nm. There are two windows of wavelength which is C band and L band. These bands allow the data signal to stimulate the excited atoms to release photons, most EDFAs are pumped by laser with a wavelength of either 980 or 1480 nm [12]. The 980 nm pump wavelength has shown their gain efficiencies around 10 dB/mW, while the 1480 nm pump wavelength provides efficiencies of around 5 dB/mW. Typical gains are on the order of 25 dB and noise figure lies between 4-5 dB with forward pumping and equivalent figure for backward pumping are 6-7 dB assuming 1480 nm pumping light was used [9]. The energy level structure of the active medium as shown in fig 2 has the forbidden-energy gap which corresponds to the energy of the incoming photons, so that the stimulated emission process is initiated. Hence, the first step in the construction of an optical amplifier is to identify suitable materials that can be used as active media in the amplifier either directly or after suitable treatment to a basic material. In the construction of an EDFA, the core of a normal optical fiber is appropriately doped with erbium

(Er3+) atoms and the energy level diagram of the doped region of the optical fiber core thus looks like:

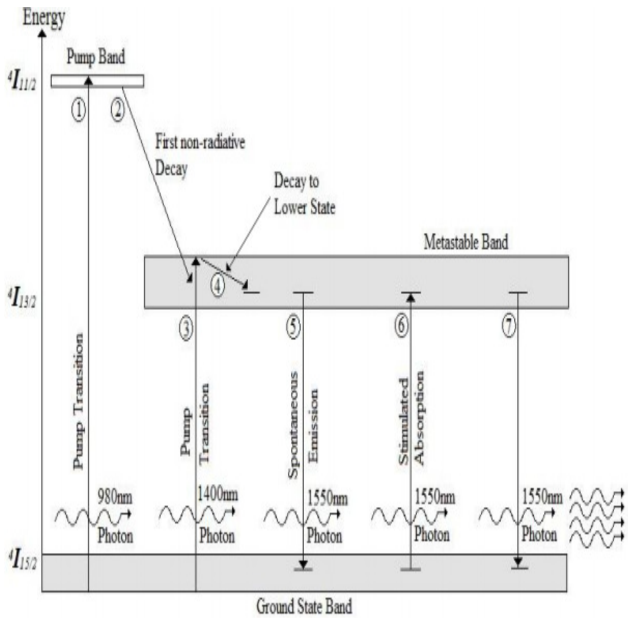

Fig. 4 Erbium Energy Diagram

As shown in fig. 4, the energy difference between the metastable and the ground states is about 1550 nm, so the EDFA operates in the 1550nm optical communication window. The metastable state acts as the lasing level in the EDFA where the electrons await stimulation from the incident optical photons to undergo stimulated emission so as to provide an amplified coherent optical output. However, due to the wide nature of the metastable band (1480nm-1560nm), two different types of pumping wavelengths may be possible viz. 980nm pump and 1480nm pump as shown in the fig. 4. But the use of a 1480nm pump poses difficulties such as higher noise and lesser separation between pump and signal wavelengths thereby creating the possibility of interference. Hence a 980nm pump which has lower noise is generally preferred. The pumped electrons to the pump band then undergo a rapid non-radiative decay to the metastable band. The time constant of this decay is of the order of micro-seconds. Once in the metastable band, the electrons in the higher metastable levels further decay down to the lower metastable levels where there are more number of energy levels available and here they wait to enrol in the process of stimulated emission [12].

Table III
Comparison between SOA and EDFA [12]:

Semiconductor Optical Amplifiers (SOA)	Erbium Doped Fiber Amplifier (EDFA)
These amplifiers are compatible in both 1300nm and1550nm optical communication windows.	These amplifiers are compatible only in the 1550nm optical communication window.
SOAs have high output optical power due to the fact that they are nothing but LASERs which, intrinsically, are optical amplifiers.	EDFAs can handle high power as well as provide a high gain (25dB).
SOAs have high coupling loss.	These amplifiers have low coupling losses as well as low noise figures
Because they are semiconductor based, SOAs can be integrated with other semiconductor based circuitry.	EDFA have low cross talk figure.
They have high non-linearity.	EDFAs are polarization-insensitive.

C. Raman Amplifier

A Raman amplifier is using the effect of Raman scattering. Raman scattering, especially if it is stimulated, is a very important non-linear effect because it affects the SNR in a WDM system. It can also be used for amplification of the optical signals in a long haul optical communication link. The spontaneous Raman scattering was discovered by Sir C. V. Raman. In case of spontaneous Raman scattering, a small portion of the incident light is transformed into a new wave with lower or higher frequency. This transformation is because of the interaction of the photon with the vibration modes of the material. The transformation efficiency of spontaneous Raman scattering is very low. Typically photons 1 part per million are transformed to the new wavelength per cm length of the medium.For optical amplification we need stimulated Raman scattering.

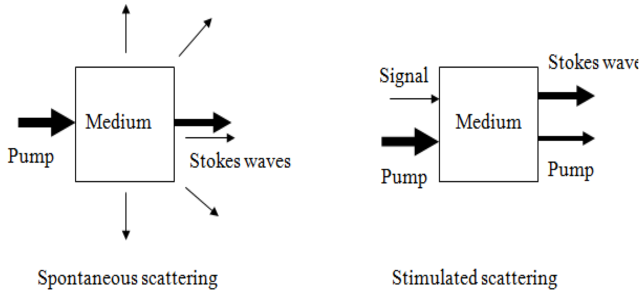

Fig. 5Spontaneous and Stimulated scattering

The basic material used in optical fiber is glass which is not crystalline but is amorphous in nature. The molecular resonance frequencies of the vibrational modes in glass are overlapped with each other to give a rather broad frequency band. The optical fibers therefore show Raman scattering over a large frequency range.The energy conversion process between the pump and the Stokes is characterized by a parameter called the Raman Gain, g_R [12]. Raman gain in optical fiber occurs from the transfer of power from one optical beam from one optical beam to another through the transfer of energy of photon and a photon arises when a beam of light couples with the vibrational modes of medium. The gain presented by the Raman Effect in fused silica glass is polarization dependent; therefore gain only occurs if both the signal and pump beams is the same polarization.

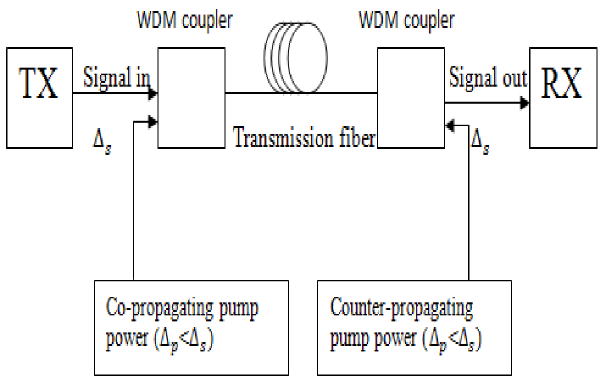

Fig. 6 Raman fiber amplifier

For the distributed Raman fiber amplifier (RFA), power is provided by optical pumping of the transmission fiber, the pump wavelength is shorter than the wavelength to be amplified by an amount that corresponds to an optical frequency difference of about 13.2 THz. The signal the experiences gain due to stimulated Raman scattering (SRS), a non-linear optical process in which a pump photon is absorbed and immediately reemitted in the form of photon and a signal photon, thus amplifying the signal as shown in fig. 6 [13].

Advantages of Raman amplifier:

1. The gain existence in every fiber.
2. The gain is resonant which is available over the entire transparency region of the fiber.
3. The gain spectrum can be tailored by adjusting the pump wavelength. For example multiple pump lines can be used to increase the optical bandwidth.
4. It is relatively broad-band amplifier with bandwidth greater than 5 THz and the gain reasonably flat over a wide wavelength range.

IV. HYBRID OPTICAL AMPLIFIER

There is one method of utilization fiber amplifiers for optimum utilization of available fiber bandwidth i.e. by a way of using various combinations of optical amplifiers in different wavelength ranges is called a hybrid amplifier. Hybrid amplifiers are the advance technology for future and are attractive in optical communication as they expand the system bandwidth in long haul transmission. Hybrid amplifier is the serial or parallel combination of two or more optical amplifier in different wavelength. In parallel configuration, the DWDM signal are first demultiplexed into several wavelength-band groups with a coupler then they are amplified by amplifier that have gain in the corresponding wavelength-band and then they are multiplexed again with a coupler. The parallel configuration is very simple and applicable to all amplifiers but it has disadvantages also e.g. an unusual wavelength region exists between each gain band originated from the guard band of the coupler and also the noise figure degrades due to the loss of the coupler located in front of each amplifier. On the other hand, the amplifiers connected in series have relatively wide gain band, because they do not require couplers [14]. It has wide gain spectrum, large signal gain, pump consumption efficiency, and effective gain bandwidth. The hybrid amplifiers can be placed before or after the link for power compensation of propagating signal.

JipsySudarsanan et al. [12] investigated the performance evaluation of different combinations of optical amplifiers which is used to increase the long haul and ultra-broadband transmission distance, cascadability and flexibility of the optical networks. The performance of optical amplifiers and hybrid amplifiers in term of the eye pattern, the output power and the Q-factor are evaluated. In the result SOA-RAMAN, SOA-EDFA-RAMAN and SOA-RAMAN-EDFA combinations provide better performance and also observed that hybrid amplifier SOA-RAMAN-EDFA provide the highest output power (31.102 dB and 22.97 dB) and better eye diagram from 40 km to 240 km compared to other optical amplifier which is valid up to 160 km and above 160 km.

Piyush Jain et al. [15] analyse the different hybrid amplifiers (RAMAN-EDFA, RAMAN-SOA, SOA-EDFA, EDFA-RAMAN-EDFA) due to varying transmission distance (10 to 200 km) at speed 10 Gbps for 16×32 and 32×10 Gbps WDM system. At the result, it is observed that EDFA-RAMAN-EDFA provides better result.

DWDM has been emerged in today's optical networks due to usage of Hybrid Optical Amplifier and the performance of DWDM system is enhanced through Hybrid Optical Amplifier.DWDM system is used to increase long haul transmission distances with improvement of bandwidth along with suppressed impairments and nonlinear effects. The biggest challenge with hybrid amplifier is to maintain and offer high bandwidth in case of higher number of channels. Hybrid Amplifiers will be designed for DWDM systems using Optical Communication software in which various combinations of optical amplifiers will be combined in series to make use of their advantages in DWDM systems. Modelling of different parameters e.g. gain, amplified spontaneous emission, BER, length of fiber and variation of output power can be performed for proposed hybrid amplifier [13].

GarimaArora et al. [16] demonstrate the comparative performance of hybrid optical amplifiers (RAMAN-EDFA, RAMAN-SOA, EDFA-SOA) for 32×10 Gbps with 0.8 nm channel spacing dense wavelength division multiplexed system and observe that RAMAN-EDFA provides highest output power of 16.086 dBm, maximum eye opening of 0.0065 and minimum bit error rate of $1.96e^{-10}$ at 224 km. In optical fiber communication system, wavelength division multiplexing (WDM) is one of the most efficient techniques to increase the information capacity.

Sunil Pratap Singh et al. [17] investigated the crosstalk reduction in WDM system using hybrid amplification technique. To reduce the crosstalk, polarization interleaved (the bit stream in two neighbouring channels are orthogonally polarized) WDM system is modified and analysed. The polarization interleaved (PI) and modified polarization interleaved system are evaluated by using the hybrid fiber amplification technique. The signal power, OSNR, noise power, and optical eye diagram are obtained for 100 GHz and 50 GHz channel spacing at 20 Gb/s and 40Gb/s bit rate.

Simranjit Singh et al. [18] investigated the performance of 64×10Gbps and 96×10Gbps DWDM system consisting of hybrid optical amplifier RAMAN-EDFA for different data format such as non-return to zero (NRZ), return to zero (RZ) and different phase shift keying (DPSK). RZ is more adversely affected by nonlinearities, whereas NRZ and DPSK are more affected by dispersion. The RZ raised cosine modulation format has the highest power levels with the minimum loss. EDFA have a high gain, operating at low pump power and their performances are better in comparison with other similar amplifiers and optical devices. EDFA have a large bandwidth, a low noise figure and polarization insensitivity. However in case of EDFA base WDM system a serious problem of un-flattened gain spectrum is observed. The gain spectrum of EDFA is broadened and flattened by cascading by EDFA and TDFA using Dynamic Gain Equalizer (DEG) [19].

V. Bobrovs et al. [14] investigated the performance improvement in long reach optical access system with hybrid optical amplifiers. The apparent options of optical amplification in wavelength division multiplexing systems included the distributed Raman amplifier, erbium doped fiber amplifier, and semiconductor optical amplifiers. It was concluded that hybrid DRA-EDFA and DRA-SOA solution may be successfully implemented in passive optical network to extend the achievable transmission distance. In this particular case the usage of RA-SOA helped to enlarge transmission from 69 km to 124 km, and the implementation of the DRA-EDFA hybrid to 126 km.

R.S.kaler [20] investigated 16 channel WDM systems at 10 Gb/s for the various optical amplifiers and hybrid optical amplifiers and the performance had been compared on the basis of transmission distance and dispersion. The amplifiers EDFA and SOA had been investigated independently and further compared with hybrid optical amplifiers like RAMAN-EDFA and RAMAN-SOA. It was observed that hybrid optical amplifier RAMAN-EDFA provides the highest output power (12.017 and 12.088 dBm) and least bit error rate (10^{-40} and 9.08×10^{-18}) at 100 km for dispersion 2 ps/nm/km and 4 ps/nm/km respectively.

Ju Han Lee et al. [21] demonstrated a novel concept of the dispersion compensating Raman/erbium-doped fiber amplifier recycling residual Raman pump for increase of overall power conversion efficiency. Using the proposed scheme, the significant enhancement of both signal gain and effective gain-bandwidth by 15 dB (small signal gain) and 20 nm, respectively, compared to the performance of the Raman- only amplifier.

V. CONCLUSION

During the last few decades, FSO technology has become one of the most discussed technologiesin telecommunication adhering to its innovation problem solving capabilities. Its performance depend upon the atmospheric turbulence in FSO channel, optical amplifier are used to amplify the optical signal. In this paper various hybrid amplifiers were studied. This study proposes the use of hybrid amplifiers in FSO system and it is observed that the Raman-EDFA is the best suitable hybrid amplifier. It gives long term success of this technology resulting accurate performance from the system.

ACKNOWLEDGMENT

The authors are first of all thankful to almighty, and also to the Guide, Faculty of Electronics and Communication, Eternal University for providing the necessary facilities for the presentation of paper.

REFRENCES

[1] MingboNiu, Julian Cheng and Jonathan F. Holzman, "Terrestrial Coherent Free-Space Optical Communication System", 2012. [Online] Available: http://dx.doi.org/10.5772/48284

[2] Priyanka Sharma, HimaniSarangal, JyoteeshMalhotra, "Detrimental Effect of Weather Conditions on FSO Based System Survey",*International Journal of Application or Innovation in Engineering and Management.* Vol.4, issue 6, pp. 74-79, 2015.

[3] Gurdeep Singh,Tanvir Singh, Vinaykant, Vasishathkaushal, "Free Space Optics: Atmospheric Effects and Back Up". *International Journal of Research in Computer Science.*Vol. 1, issue 1, pp. 25-30, 2011.

[4] Recommendation ITU-R P.1814. 2007. Prediction methods required for the design of terrestrial free-space optical links, 2012.

[5] AjaybeerKaur, Dr. M. L. Singh, "Comparing the effect of Fog and Snow Induced attenuation on Free Space Optics (FSO) and RF Links",*International Journal of Computer Science Trends and Technology.*Vol. 3, issue 1, pp. 554-556, 2012.

[6] Shruti R, SonaliChugh, Nicky Niranjan, C. Ramachandran and M.K.Jain, "Free Space Optics (FSO): Present Scenario and Developments",*HCTL Open Science and Technology Letters (HCTL Open STL).* Vol. 4, pp.1-6, 2014.

[7] Scott Bloom, "The Physics of Free Space Optics". Air Fiber Inc.2, 2002.

[8] www.fsona.com

[9] G.P.Agrawal, "Fiber Optic Communication system". Johan wiley and Sons, New York, 2011.

[10] G. Keiser, 'Coherent optical fiber communication', Optical fiber communications, McGraw-Hill, New York, Pp: 376-396, 1991.

[11] Niloy K Datta and Qiang, "Semiconductor Optical Amplifiers". World Scientific, London, Pp 6, 2006.

[12] Professor R.K Shevgaonkar

[13] Biswanath Mukherjee, “Optical WDM networks”. Springer, New York, 2006.

[14] InderpreetKaur, Neena Gupta, “Hybrid Fiber Amplifier”. Rayat and bahara institute of engineering, Mohali, PEC University of Technology, Chandigarh. Pp. 104-122

[15] JipsySudarsanan, Vidya Raj, “Performance Evaluation of Hybrid Amplifier”, *IJSRD-International Journal for Scientific Research and Development.* vol.2 issue 2 pp. 55-58 (2014).

[16] Piyushjain, Mr.BipanKaushal, Shrija Jain, “Performance Analysis of Different Hybrid Optical Amplifier due to Varying Transmission Distance at 10 Gbps”. *International Journal of Emerging Technology in Computational and Applied Science (IJETCAS)* 5 issue 3 pp. 246-240, 2013.

[17] GarimaArora, SanjeevDewra, “DWDM Transmission Using Hybrid Optical Amplifiers”, *International Journal of Advanced Research in Computer and Communication Engineering. Vol.* 3 issue 4 pp. 6174-6177, 2014.

[18] Sunil Partap Singh, Abhinay Kumar Sharma, Nar Singh, “Crosstalk Reduction in WDM System Using Hybrid Amplification Technique”, *Optics Communications.*Vol.285 issue 19 pp.3931-3934, 2012.

[19] Simranjit Singh, R.S.Kaler, “Performance Evaluation of 64×10 Gbps and 96×10 Gbps DWDM System with Hybrid Optical Amplifier for Different Modulation Formats”, *Optik-International Journal for Light and Electron Optics.*Vol.123 issue 24 pp. 2199-2203, 2012.

[20] V. Bobrovs, S. Olonkins, O. Ozolins, J. Porins, “Hybrid Optical Amplifiers for Flexible Development in Long Reach Optical Access System”, *IEEE Xplore Digital Library*. Pp. 577-582, 2012.

[21] R.S. Kaler, “Simulation of 16×10 Gb/S WDM System Based on Optical Amplifiers at Different Transmission Distance and Dispersion”, *Optik - International Journal for Light and Electron Optics.* Vol. 123, issue 18, pp. 1654-1658, September 2012.

[22] J. Lee, Y. Chang, Y. G. Han, S. Kim, “Dispersion-Compensating Raman/EDFA Hybrid Amplifier Recycling Residual Raman Pump for Efficiency Enhancement”, *IEEE Xplore Digital Library.* Vol. 17, issue 1, pp. 43-45, 2004.