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Design and performance analysis of FSO (free space optical) networks

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Abstract- *In today's world, the communication has become an integrally of every human. FSO is a line of sight wireless communication system in which the data is transmitted in the form of laser beams. FSO is one of the best communication system because of its highest bandwidth, no need of licensing, maximum transmission data rates with very high security. Since the signal is transmitted via free space, the laser beams are degraded due to turbulent atmosphere.The main aim of this module is to first design a single channel FSO trans-receiver system and then upgrade it to higher number of channels (upto 30 channels). After the design is done and validated multiple simulations are carried out to evaluate the effects/phenomena that limit the performance of the proposed designs and extend their effects on performance evaluating parameters. Then different techniques are proposed that improve the performance evaluating parameters and either eliminate or minimize the effect of noise and distortion effects onto system performance.*

Keywords:- *Free space optics(FSO), Return-to-zero (RZ), Non return-to-zero(NRZ), Performance evaluating parameters(PEP), pseudo random code generator(PRBS), Photodiode(PD).*

I. INTRODUCTION

FSO is one of the wireless transmission link in which data is transmitted in the form of infrared rays or laser beams via free space instead of fiber as in case of fiber optic communication system. FSO transmission system is the best because of its various advantages which include higher bandwidth, easier installation, low cost, no spectrum lisence and higher security[1]. FSO supports maximum data rate of up to 2.5 Gbps unlike RF communication system which supports only data transfer rate of about 622 Mbps.Data transmission using FSO system is very simple as it only requires a transmitter and a receiver section connected via free space.fso can be used to transmit voice, video and data using air as the medium of transmission.

II. What is FSO

Free space optical transmission system is a line of sight wireless communication system in which data is transmitted in the form of laser beams or infrared beam(invisible) via free space to obtain broadband communication.

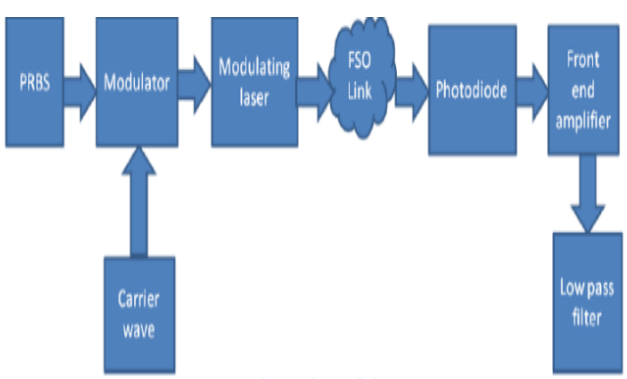

Fig 1: Basic FSO link

In FSO the data to be transmitted modulates the laser beam generated by high power LED or LASER and then this modulated signal is transmitted using air as transmission medium. FSO system consists of a transmitter section and a receiver section connected by the free space link (atmosphere).

Transmitter section has various subsystems which include pseudorandom binary (PN) sequence generator which generates the random binary sequence which acts as data to be transmitted.

The output of PN sequence acts as input to encoder (return-to-zero (RZ), non return-to- zero(NRZ) etc) which makes electrical pulses of the transmitted signal using line coding. These electrical pulses are used to modulate the laser beam generated by a high power LASER or LED. This laser beam acts as a carrier for transmitting the data. Machzehnder optical modulator is used for this purpose. The type of modulation depends upon the distance between the transmitter and the receiver. Then this modulated signal is given to telescope to have long distance transmission through free space[2]. The transmitted signal is picked up by the receiver telescope and is then given to the photo diode which converts the optical signal back to the electrical signal which is then amplified and is then passed through low pass filter to retrieve the original signal at the receiver end. Basically, the receiver is used to regenerate electrical signal of original transmitted and modulated signal[3].

The quality and stability of the link between the transmitter and the receiver depends upon the atmospheric factors such as fog, dust, rain and heat etc.

To establish a FSO communication link we need to have the knowledge about the distance between the transmitter and the receiver, atmospheric conditions, line of sight etc.

III. Compensation techniques

(A) Optical amplifiers:

An optical amplifier is a device that amplifies the signal directly without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Before optical amplifiers, regenerators were used. These regenerators used to convert the optical signal into electronic domain, cleaning and amplifying it and then retransmitting it in the optical domain. Bit rate dependency and modulation format dependency were the main drawbacks of these regenerators.

Optical amplifiers can be classified as

- EDFA
- Raman amplifiers
- Semiconductor optical amplifier (SOA)

  All these optical amplifiers work on the principle of stimulated emissions.

IV. Analysis and modelling of simulation setups:

(A) General transmitter-receiver free space optical link

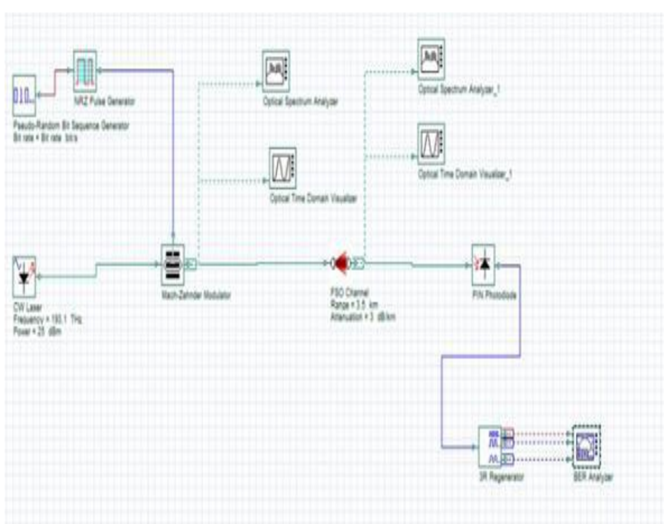

Fig 2: Transmitter receiver FSO link

Description: Figure shows general bidirectional optical fibre link. In this bidirectional optical transmitter link one side acts as transmitter and other acts as receiver and vice-versa i.e. data is transmitted in both the directions simultaneously. In this optical transmitter receiver link the data to be transmitted is produced by pseudo-random generator that is converted into digital signal using NRZ Generator. The optical carrier wave that is used to modulate digital signal is produced by continuous wave laser. The optical carrier wave and the signal to be transmitted are given to Mach Modulator that produces the modulated optical signal. The Mach-Zehnder modulator is an intensity modulator based on an interferometric principle. The signal is allowed to travel through atmosphere. After the signal has travelled the desired distance the modulated signal is allowed to pass through the photo detector pin that extracts the original signal from modulated signal The original signal and the optical carrier signal is displayed with the help of oscilloscope visualizer and optical time analyzer respectively. The same process is repeated on the other side simultaneously.

B) 30 channel SOA set up for FSO link

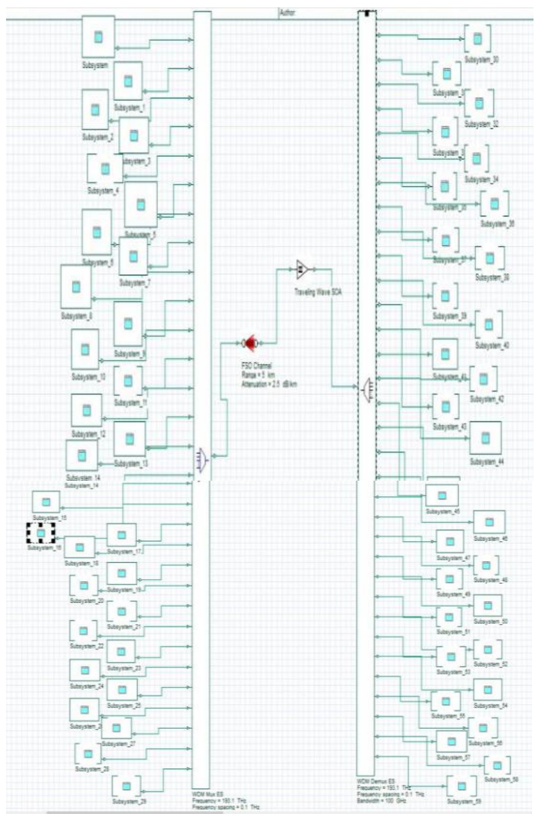

Fig 3: 30 channel setup with SOA

Description: A 30 channel set up is shown above in which the overall performance of FSO system has been increased by making use of a travelling wave SOA. Semiconductor optical amplifiers (SOAs) are amplifiers which use a semiconductor to provide the gain medium. They are typically made from GaAs/AlGaAs, InP/InGaAs, InP/InGaAsP and InP/InAlGaAs. The BER visualize output shows that with increase in FSO length the BER values decreases which means that by making use of an SOA in the FSO link data can be transmitted over longer distances.

(C) 30 channel EDFA setup for FSO link

Description: A 30 channel set up with EDFA is shown below. It consists of an EDFA at the output of WDM multiplexer to increase the system performance. The erbium-doped fibre amplifier (EDFA) is the most deployed fibre amplifier as its amplification window coincides with the third transmission window of silica-based optical fibre. The erbium doped amplifier is a high gain amplifier. An EDFA based FSO system supports signal transmission over longer distances than that of a single channel system.

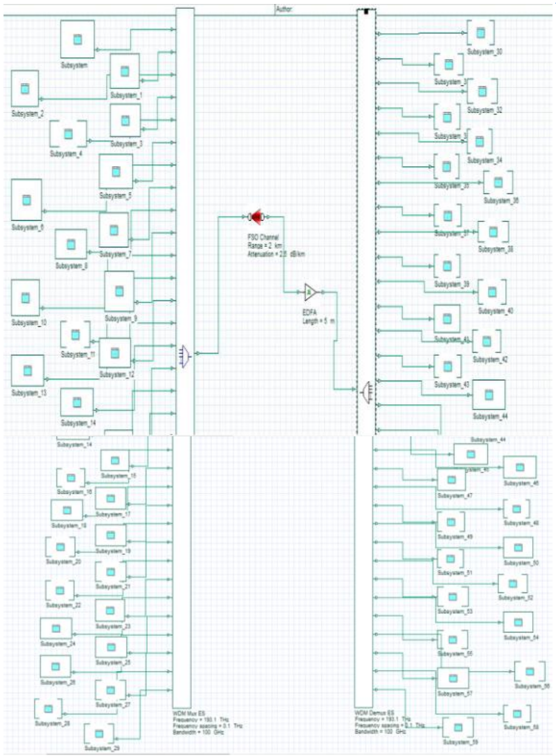

Fig 4: 30 channel setup with EDFA

(D) 30 Channel EDFA Plus SOA setup for FSO link

Description: Figure below shows a hybrid setup in which both EDFA and SOA amplifiers are used. By making use of both SOA and EDFA in a single system signal can be transmitted efficiently over moderate distances.

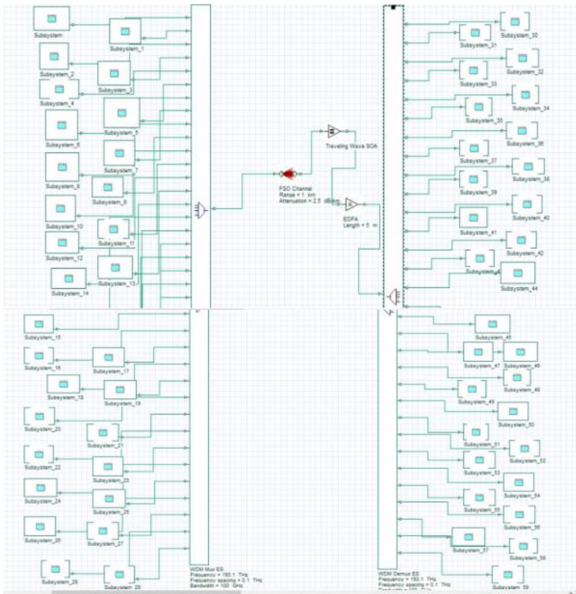

Fig 5: 30 channel setup with EDFA plus SOA

(E) 30 channel setup with pre Compensation technique

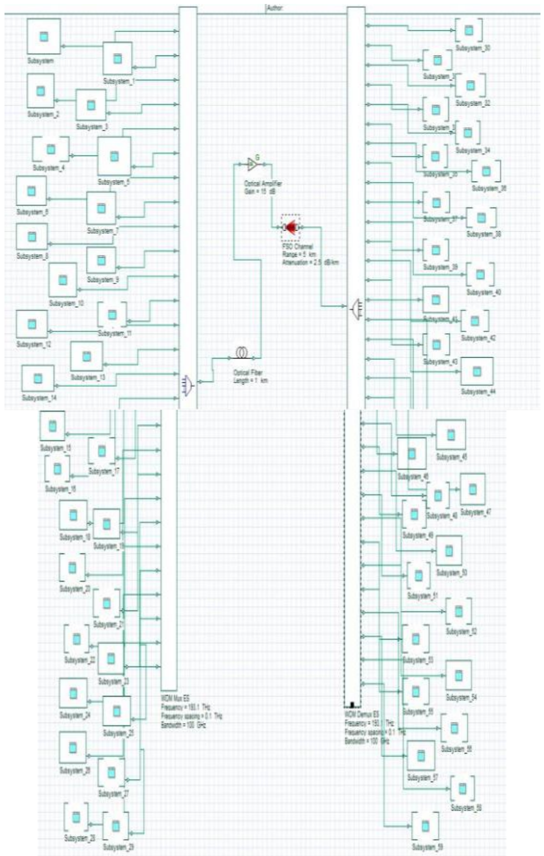

Fig 6: 30 channel setup with pre compensation

Description: In order to improve overall system performance and increase the transmission distance, several compensation techniques were proposed. In pre-compensation, the optical communication system is pre compensated by an optical amplifier. The transmitter section consists of data source, modulator driver (NRZ driver), laser source (CW laser) and amplitude modulator. Data source produces a pseudo-random sequence. The output of source is given to modulator driver which produces NRZ format pulse. The output of laser source is CW type. The modulator is of Mach-Zehnder modulators. At the receiver side, the optical signal is transformed in to an electrical signal by a PIN photodiode. The BER analyzer is used to depict corresponding value of BER; Eye height etc. The BER output shows an improved performance to that of uncompensated set up.

(F) 30 channel setup with post compensation technique

Description: In order to improve overall system performance and increase the transmission distance, several compensation techniques were proposed. In post-compensation, the optical communication system is post compensated by an optical amplifier. The transmitter section consists of data source, modulator driver (NRZ driver), laser source (CW laser) and amplitude modulator. Data source produces a pseudo-random sequence. The output of data source is given to modulator driver which produces NRZ format pulse. The output of laser source is CW type. The modulator is of Mach-Zehnder modulators. At the receiver side, the optical signal is transformed in to an electrical signal by a PIN photodiode. The BER analyzer is used to depict corresponding value of BER; Eye height etc. The BER output shows an improved performance to that of uncompensated set up.

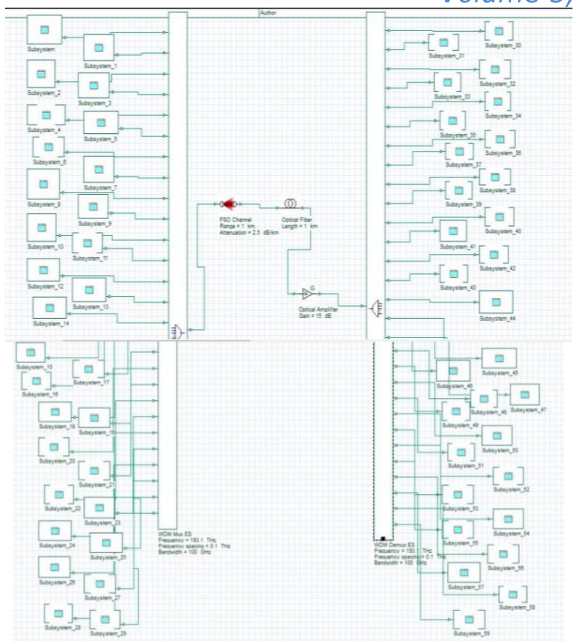

Fig 7: 30 channel setup with post compensation

(G) 30 channel setup with pre-post compensation technique

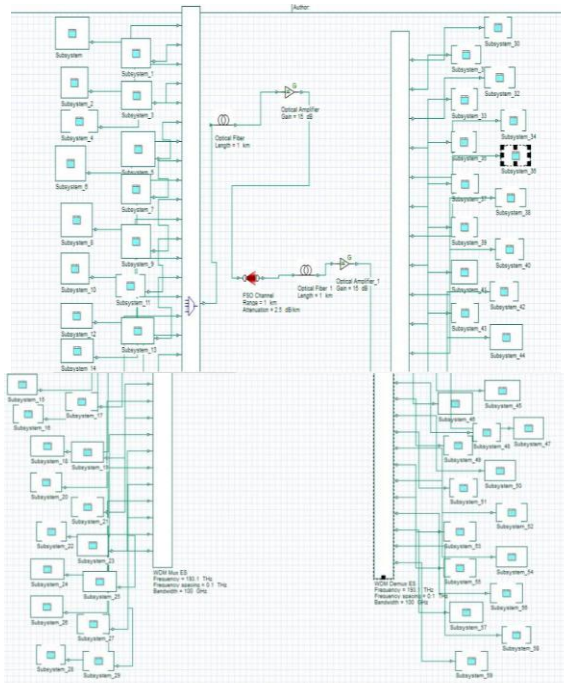

Fig 8: 30 channel setup with pre-post compensation

Description: In this case to increase the overall performance and transmission distance a FSO link has both pre compensated as well as post compensated by optical amplifiers. The transmitter section consists of 30 subsystems each consisting of data source, modulator driver (NRZ driver), laser source (CW laser) and amplitude modulator. Data source produces a pseudo-random sequence. The output of data source is given to modulator driver which produces NRZ format pulse. The output of laser source is CW type. The modulator is of Mach-Zehnder modulators. At the receiver side 30 subsystems are used each consisting of a PIN photodiode, Bessel filter, 3R regenerator and BER analyzer. The optical signal is transformed in to an electrical signal by a PIN photodiode. The BER analyzer is used to depict corresponding value of BER, Eye height etc. The

BER output shows an improved performance to that of uncompensated set up. Pre-post compensation is also called as symmetric compensation technique.

(V) Graphs and discussions

The retrieved data from multiple simulations was plotted using origin 8. The evaluated graphs are shown as follows:

(A) Graph 1 (Unamplified technique)

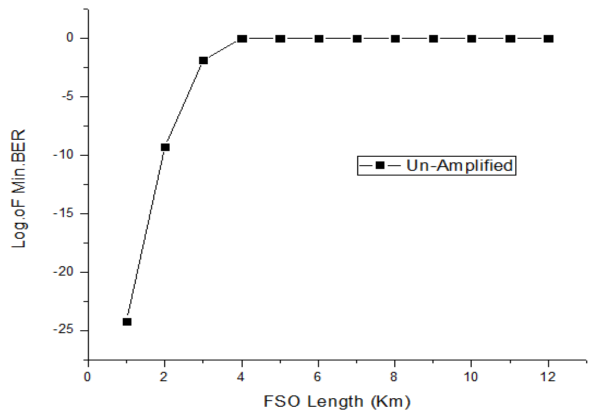

Fig 9: Log. of Min. BER VS FSO length(unamplified)

Performance evaluating parameters obtained against variable FSO length are plotted for 30 channel unamplified setup. The interfaces drawn from the graph are as follows:
i)BER values show an increase with increase in FSO length.
ii)The maximum FSO length that was supported by the setup was to a maximum of 2 kilometers
iii)Beyond a FSO length of 5 kilometers the transmission was severely degraded.

B) Graph 2 (EDFA Based)

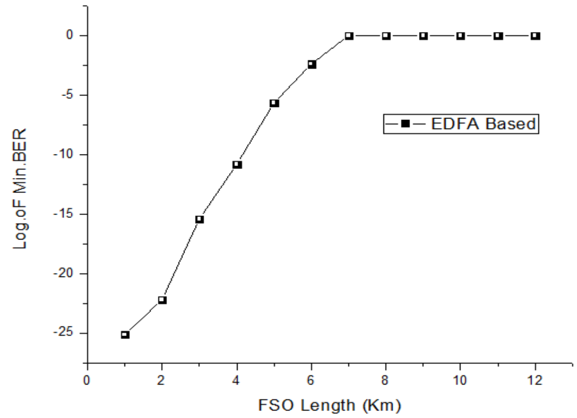

Fig 10: log. of Min.BER VS FSO length(EDFA)

The original setup was subjected to amplification using EDFA. The PEP were plotted against variable FSO length. The interfaces drawn from the graph are as follows:
i)BER values show an increase with increase in FSO length.
ii)The maximum FSO length that was supported by the system within permissible limits got increased to 5 to 6 kilometers.
iii)Beyond 7 kilometers of FSO length the system developed severe performance degradations.

(C) Graph 3 (SOA Based)

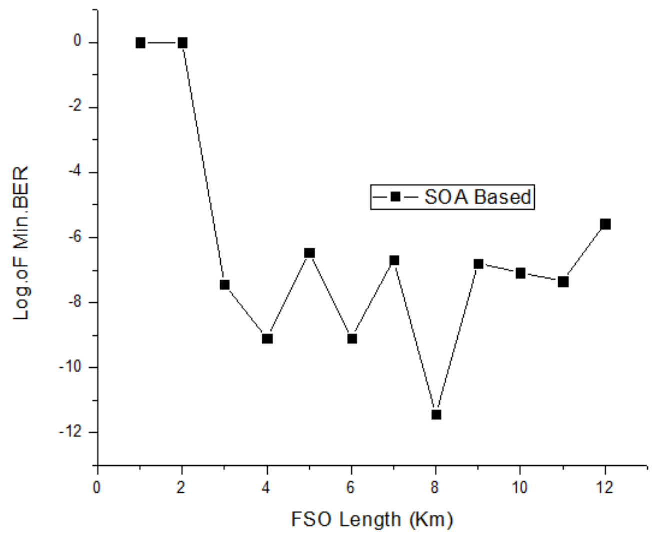

Fig 11: Log . Of Min.BER VS FSO length (SOA)

i)As the Transmission length increases the system performance improves after transmission through SOA based amplifiers.
ii)The performance however first increases and then shows a fluctuating decrease for longer FSO lengths
iii)The minimum BER was obtained at FSO length of 8 kilometers.'
iv)The maximum FSO length supported by system is between 8 to 10 kilometers.
v)After FSO length of 12 kilometers the system performance starts degrading beyond permissible limits.

D) Graph 4 (Hybrid)

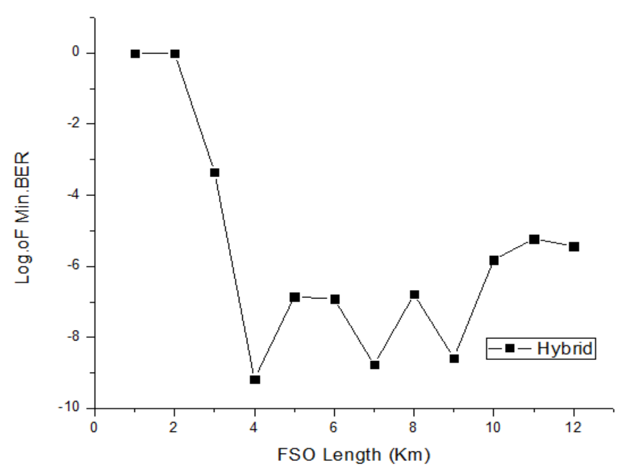

Fig 12: log. of Min.BER VS FSO length (hybrid)

The setup was subjected to hybrid amplification mechanism. The PEP thus retrieved were plotted against variable FSO length. The inferences drawn from the obtained graph are as follows:
i) As the Transmission length increases the system performance improves after transmission through SOA based amplifiers.
ii)The minimum BER was obtained at an FSO length of 4 kilometers.
iii)The maximum FSO length for such a system within which the performance stays within permissible limits was found out to be 4 to 9 kilometers.
iv)After FSO length of 12 kilometers,the system performance starts degrading beyond permissible limits.

(E) Graph 5 (comparison between various amplification techniques)

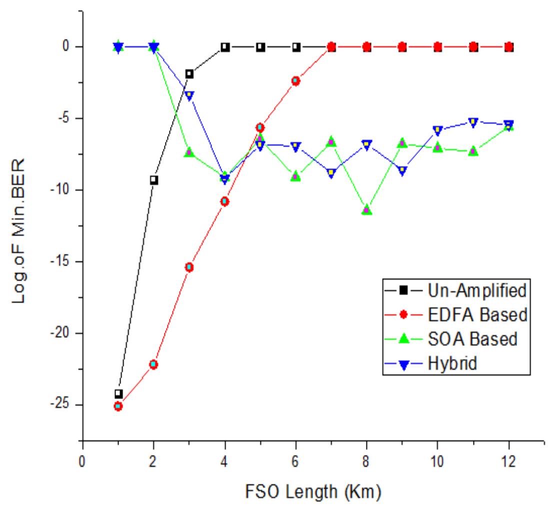

Fig 13: Log .of Min.BER VS FSO Length (comparison)

A mutual comparision for various proposed amplification techniques was drawn. The inferences drawn are as follows:
i)It was observed that there is considerable performance improvements in the proposed design by incorporating various amplification techniques.
ii)Out of all the proposed amplification techniques, SOA proves to be the best amplification technique for longer distances of transmission while as EDFA proves to be best amplification mechanism for shorter distances of transmission.
iii)For moderate distances of transmission hybrid amplification is ideal with almost flat performance for longer transmission lengths.

(F) Graph 10(pre compensation technique)

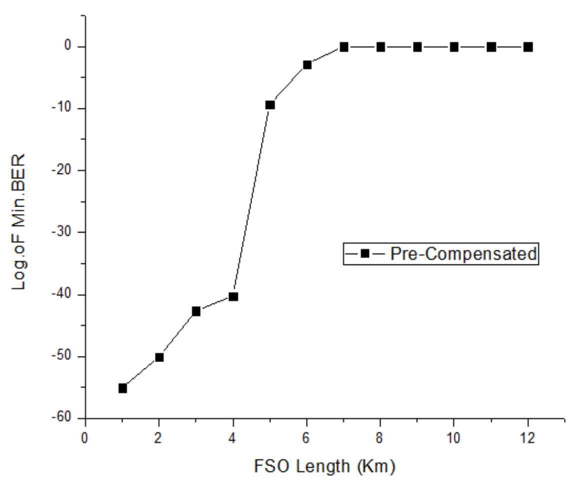

Fig 14: Log .of Min.BER VS FSO length (PRE COMPENSATION)

The graph of performance evaluating parameters obtained against variable fso lengths for a channel setup incorporating pre-compensation technique was plotted, the inferences drawn are as follows:
i)The BER values show a non-linear rise with increase in fso length
ii)Min BER of the order of 10^-51 was obtained at fso length of 1km
iii) The max BER was obtained beyond fso lengths of 7km
iv)Beyond fso lengths of 8km systems performance was severely affected.

(G) Graph 11 (Post compensation technique)

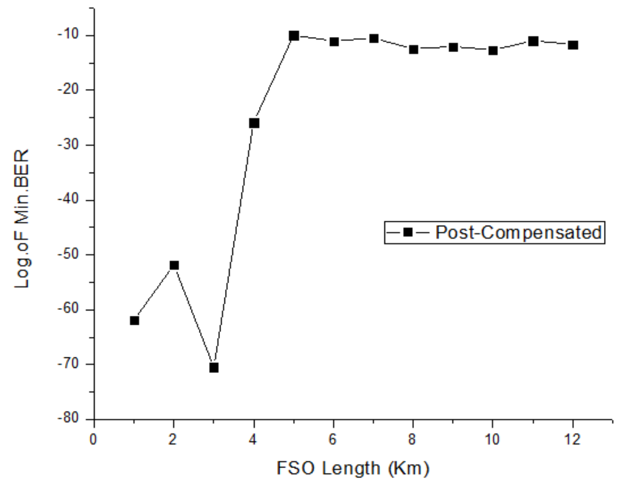

Fig 15: Log. Of Min.BER VS FSO length (POST COMPENSATION)

A graph of minimum BER Verses variable FSO length for post compensated setup was plotted the interferences drawn are as follows:
i)The minimum BER gradually increases with increase in FSO length.
ii)Minimum BER was obtained at FSO length of 3 kilometers.
iii)Beyond FSO length of 6 kilometers, the BER remains almost constant with small decline.
iv)Beyond FSO length of 12 kilometers the BER shows drastic degradation.

H) Graph 12 (symmetric compensation technique)

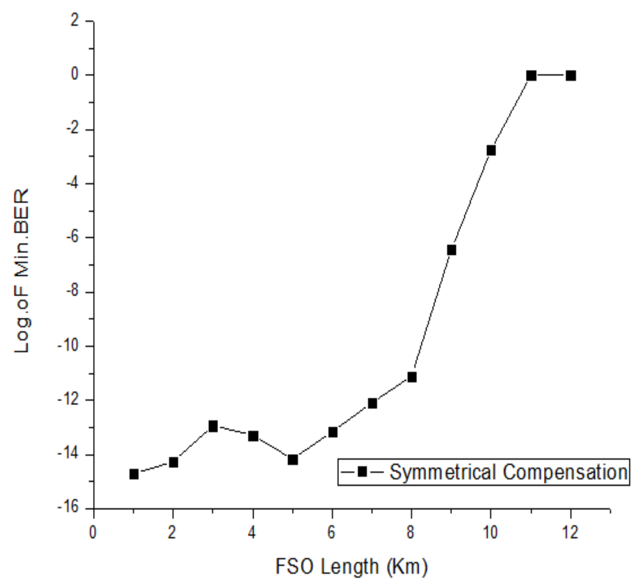

fig 16:Log.of Min.BER VS FSO length(SYMMETRIC COMPENSATION)

The BER values for a 30 channel setup incorporating symmetric compensation technique was plotted the interferences are drawn as follows:
i) The BER shows a linear rise with increase in FSO length .
ii) Minimum BER of the length of order 10-15 was obtained at an FSO length of 1 kilometer.
iii) Maximum BER was obtained beyond FSO length of 11 kilometers where the signal distorts completely.

(I) Graph 13 (Comparison of various compensation techniques)

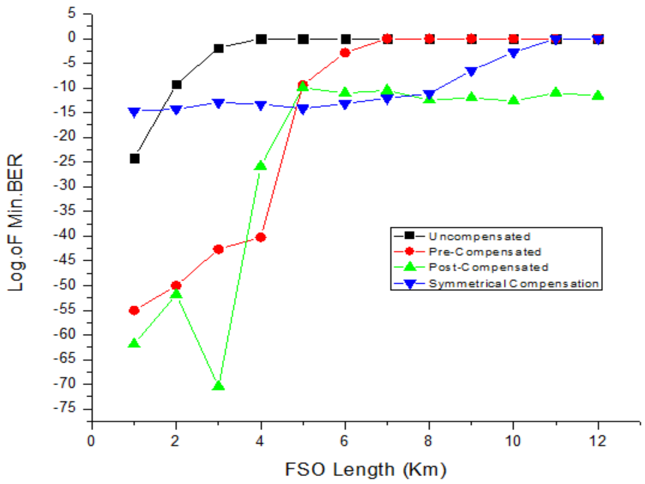

Fig 17: Log. Of Min.BER VS FSO length (COMPARISION)

The performance evaluating parameters obtained for various comparison techniques were mutually plotted against variable FSO length, the inference drawn are as follows:
i) Port compensation technique yields minimum BER and supports larger FSO length.
ii) Symmetrical compensation technique produces a near flat BER response against variable FSO length.
iii) The minimum BER of the order of 10-71 was obtained for post compensated setup at FSO length of 3 kilometers.
iv) The maximum BER was obtained for uncompensated and pre compensated setups beyond FSO length of 8 kilometers.

VI. Conclusion

In this project it was concluded that the performance of FSO systems can largely be improved using the proposed techniques. By proposing the compensation techniques like pre, post and symmetrical techniques the performance parameters showed considerable improvements by limiting dispersion, extending range and reducing distortion. Moreover a mutual comparison between hybrid and individual optical amplification techniques was made which showed SOA techniques a favorite for longer ranges while as EDFA for shorter ranges.

VII. Future scope

In future the work can be extended by working on limiting the effect of geometric losses incurred in FSO channels. Moreover work can also be extended for increasing the FSO range, supported data rates and increasing the number of data channels sending data simultaneously so as to make FSO networks a first choice for fast setup high speed communication solutions proposed for last mile.

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