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A comprehensive study of dispersion compensation in long haul optical fiber transmission system

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***Abstract*---**As Optical fiber transmission system is growing very rapidly, it becomes necessary to attain high speed data transmission as well as high data rate. Despite Optical fiber transmission systems having several features and advantages, dispersion still remain a main challenge. In this paper we use Acousto Optical Filter (AOF) and Fiber Bragg Grating (FBG) to eliminate dispersion in a long haul Optical fiber transmission system. The simulation program is operated at a speed of 10 Gbps for a range of 100Km to 300 Km optical fiber length with different input parameters like optical input power, fiber length and dispersion. The output parameters are analyzed in terms of BER, Q-factor and Eye diagram. A comparison is made between the proposed design and the existing system design.

***Keywords*---**Acousto Optical Filter, Dispersion, Fiber Bragg Grating, BER, Q-factor, Eye diagram and WDM

1. Introduction

The evolution of high speed Internet traffic and wireless communications has a significant demand for large capacity and cost effective optical fiber communication technologies. The next generation of communication technology has seen an exponential growth in the number of subscribers and high speed data transmission. The Optical fiber transmission system supports long distance communication with larger bandwidth. But long distance transmission encounters severe nonlinearities such as noise and dispersion. Hence one of the

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biggest challenges in today's Optical fiber transmission system is the minimization of dispersion.

2. The Long haul Optical Fiber Transmission System

The basic block diagram of a long haul Optical fiber transmission system is as shown in Fig. 1. At the transmitter side, the digital data from a PRBS Generator is fed to a NRZ encoder which generates a pulse according

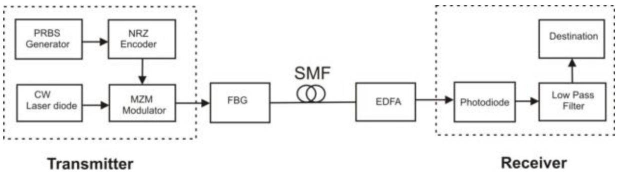


Fig. 1 Block diagram of a long haul Optical Fiber Transmission System

To the PRBS sequence. The light from CW laser is then fed to a Mach-Zehender modulator (MZM) for optical modulation. The optically modulated signal is now sent over a Single Mode Fiber link. An EDFA (Erbium doped fiber amplifier) is used to amplify the weak signal and a FBG (Fiber Bragg Grating) is used to remove dispersion. At the receiver side, a photodiode converts the optical signal back to an equivalent electrical signal and a Low pass filter removes the noise and other nonlinear effects before sending it to the destination.

3. System Design

The Schematic diagram of a long haul Optical fiber transmission system without and with Acousto Optical Filter (AOF) along with FBG dispersion compensator is as shown in Fig. 2(a) and Fig. 2(b). The number of input channels can be increased further depending on the requirement. The main components used in the proposed design are as follows:

1) Pseudo Random Bit Sequence number generator (PRBS) with a bit rate of 10 Gbps.
2) NRZ coding to generate a pulse in accordance with PRBS sequence.
3) CW Laser operating at 193.1 THz for better performance.
4) Mach Zehender Modulator (MZM) for optical modulation.
5) Single Mode Fiber (SMF) of length varying from
6) 100 Km to 300 Km.
7) Fiber Bragg Grating (FBG) for minimizing dispersion effects.
8) Acousto Optical Filter (AOF) that simultaneously modulates the wavelength and amplitude of the Laser light from multiple light sources.
9) Erbium Doped Fiber Amplifier (EDFA) to amplify weak optical signal.
10) PIN photodiode to convert the optical signal to an equivalent electrical signal.
11) BER Analyzer, Eye diagram analyzer, RF spectrum analyzer and Oscilloscope visualizer to measure the performance of the Receiver.

First, the simulation is done for the Optical fiber transmission system with only FBG Dispersion Compensator as shown in Fig.2(a) and later the simulation is done for a combination of both AOF and FBG Dispersion Compensator as shown in Fig. 2(b).The results are tabulated as shown in Table I. The eye diagrams for both the cases are shown in Fig. 3(a) and Fig. 3(b) respectively.

The 100 GHz carrier signal is selected since it is free of cost and the operation can also reach to the range of Terahertz. At the transmitter side, Pseudo-Random Bit Sequence (PRBS) generator generates binary data at 10 Gbps with a carrier frequency of 100 GHz which is then fed to non return to zero (NRZ) pulse generator to obtain the baseband signal. It is then optically modulated using MZM modulator. High frequency Carrier signal and NRZ pulse coding techniques are used for long distance communication. The Continuous Wave (CW) lasers with 1dB power emit light at frequencies 193.1 THz. Multiple lasers can be used for multiple channel communication. The MZM provides optical modulation, by using a high-frequency optical carrier signal obtained from the CW lasers and then later sent over SMF of length 100 Km.

Here SMF is used instead of multi-mode fiber (MMF) AOF is used in this network. The FBG operates with a bandwidth of 125 GHz and dispersion rate of -800 ps/ nm. At receiver side, the optically modulated signal is fed to APD (Avalanche photo diode) which converts the optical signal back to electrical signal. The electrical signal is then passed through low pass Bessel filter, 3-R generator and finally to BER analyzer, RF spectrum analyzer, Eye diagram analyzer and Oscilloscope visualizer. The low pass Bessel filter removes the noise and other nonlinear effects. The 3R regenerator generates the original electrical signal so that the BER and Q-factor are analyzed using BER analyzer. The eye diagram analyzer shows the eye diagram for eye pattern measurements. Optical power meters are also employed to measure the since SMF is capable of carrying optical signal for longer distances at higher data rate, irrespective of non-linear effects and dispersion. As the signal propagates through the optical fiber, their intensity reduces due to dispersion and attenuation. Hence Erbium Doped Fiber Amplifiers (EDFAs) are used to amplify the weak signal with minimum channel noise. It operates at a gain of 25 dB and noise figure of -4 dB. To compensate for dispersion and attenuation losses, FBG (Fiber Bragg Grating) along with impact of the non linear effects.

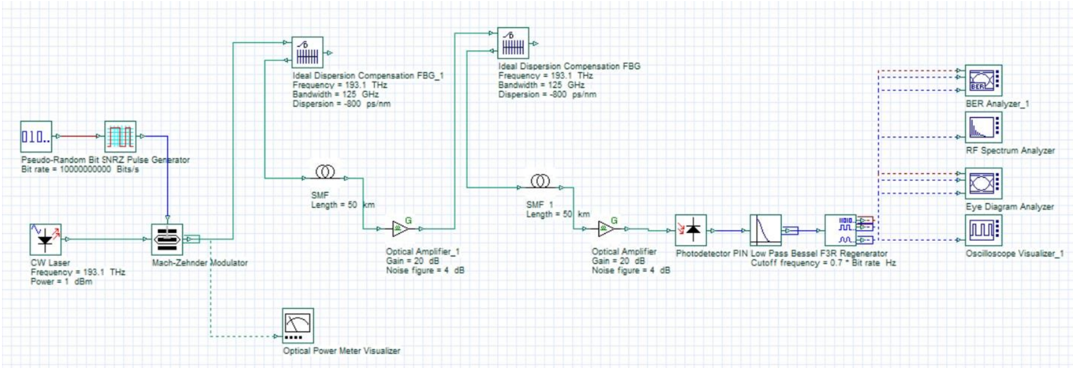


Fig. 2(a) An Optical fiber transmission System with only FBG Dispersion Compensator

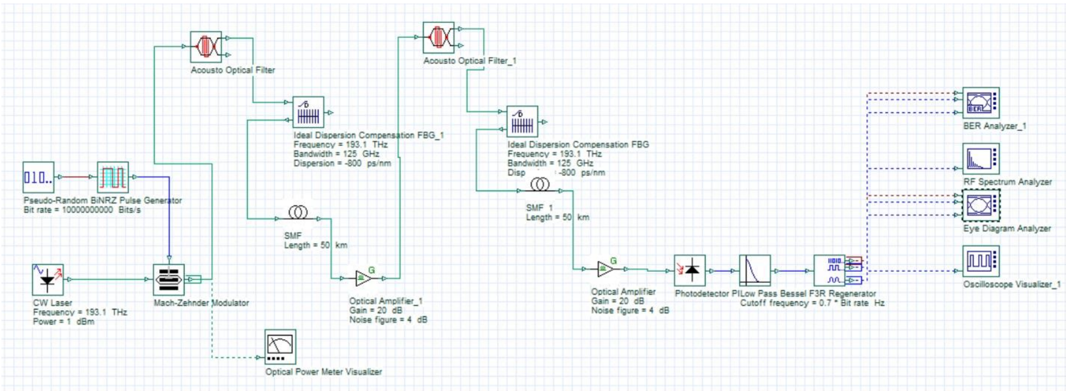


Fig. 2(b) An Optical fiber transmission System with AOF and FBG Dispersion Compensator

of a long haul Optical fiber transmission system without and with AOF. The Optical fiber transmission System without AOF shows high BER of 5.625 x 10^{-155} and a low Q-factor of 26.48 with an eye height of 0.117. With the use of AOF, results show a low BER of 3.075 x 10^{-168} and high Q-factor of 27.61 with an eye height of 0.118 which is found to better than the former. Hence the Optical fiber transmission system using AOF is found to be much more efficient.

Table II shows the receiver performance for various Input power (P_{in}) at Carrier frequency (f_c) = 50 GHz operated with both AOF and FBG Dispersion Compensator. The input power (P_{in}) is varied from + 15dBm to −15 dBm in steps of 5 dBm. The Q-factor value decreases and increase as input power (P_{in}) varies. For a particular value of P_{in} = -10dBm, the Q-factor attains maximum value of 37.39 with minimum BER value being 2.536 x 10^{-306}. Hence better performance is achieved when the input power (P_{in}) is maintained at – 10 dBm. Also Fig. 4(a) shows the variation of Input Power (P_{in}) Vs Q-factor at Carrier Frequency (f_c) = 50 GHz.

Table III shows the receiver performance for various Input power (P_{in}) at Carrier frequency (f_c) = 100 GHz

4. Results and Discussion

As the length of optical fiber increases, dispersion and attenuation losses increase. By using Fiber Bragg Grating (FBG), dispersion can be compensated. But using a combination of both AOF and FBG, dispersion can be further reduced. Table I shows the Receiver performance operated with both AOF and FBG Dispersion Compensator. The input power (P_{in}) is varied from +15dBm to −15 dBm in steps of 5 dBm. The Q-factor value increases linearly as input power (P_{in}) varies and for a particular value of P_{in} = -10dBm, the Q- factor attains maximum value of 38.75 with BER value being 0. Hence better performance is seen when the input power (P_{in}) is maintained at –10 dBm. Also Fig. 4(b) shows the variation of Input Power (P_{in}) Vs Q-factor at Carrier Frequency (f_c) = 100 GHz. Fig 5(a) shows the variation of Input Power (P_{in}) Vs Frequency (Hz) as viewed on the RF Spectrum Analyzer.

Table IV shows the receiver performance for various distance ranging from 100 Km to 300 Km. For an Input power (P_{in}) = – 10 dBm and Carrier frequency (f_c) = 100 GHz, the Q-factor reduces and BER increases as distance increases. The eye height also reduces to zero. At a distance of 100 Km, Q-factor is found to have a maximum value of 38.75 which decreases as distance increases. The Q-factor decreases with increase in BER as the number of channels increases. Hence selection of proper

Table I: Receiver performance of an Optical fiber transmission system without and with AOF in combination with FBG Dispersion Compensator

SL	Acousto Optical Filter	Q- factor	BER	Eye Height	Threshold
1	Without	26.48	5.625×10^{-155}	0.117	0.021
2	With	27.61	3.075×10^{-168}	0.118	0.019

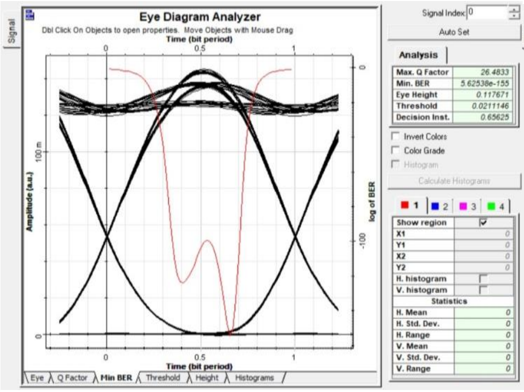


Fig. 3(a) Eye Diagram of an Optical fiber transmission System with only FBG Dispersion Compensator

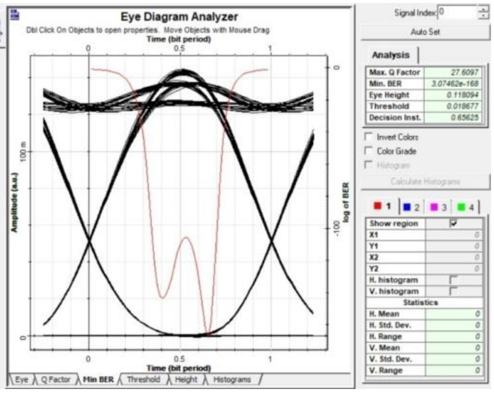


Fig. 3(b) Eye Diagram of an Optical fiber transmission system with AOF and FBG Dispersion Compensator

Table II: Receiver performance for various Input power (P_{in}) at Carrier frequency (f_c) = 50 GHz in combination with AOF and FBG Dispersion Compensator

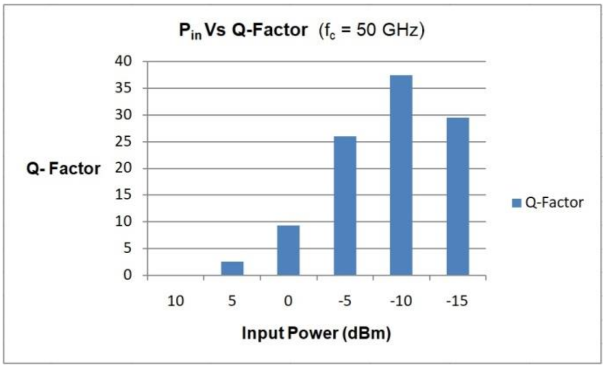
Sl	Input Power (P_{in})	Q-factor	BER	Eye Height	Threshold
1	+ 15 dBm	2.826	0.0024	-2.628	70.94
2	+ 10 dBm	0	1	0	0
3	+ 5 dBm	2.53	0.0049	- 1.447	9.33
4	0 dBm	9.328	3.689×10^{-21}	1.578	0.281
5	- 5 dBm	25.96	4.51×10^{-149}	0.572	0.099
6	- 10 dBm	37.39	2.536×10^{-306}	0.186	0.042
7	- 15 dBm	29.48	1.576×10^{-191}	0.057	0.0052

Table III: Receiver performance for various Input power (P_{in}) at Carrier frequency (f_c) = 100 GHz in combination with AOF and FBG Dispersion Compensator

Sl	Input Power (P_{in})	Q-factor	BER	Eye Height	Threshold
1	+ 15 dBm	0	1	0	0
2	+ 10 dBm	0	1	0	0
3	+ 5 dBm	2.26	0.0114	- 0.978	1.59
4	0 dBm	8.82	4.354×10^{-19}	0.939	0.236
5	- 5 dBm	26.41	4.125×10^{-154}	0.350	0.061
6	- 10 dBm	38.75	0	0.113	0.0078
7	- 15 dBm	26.60	2.987×10^{-156}	0.034	0.0038

Table IV: Receiver performance at various distances for Input power (P_{in}) = – 10 dBm and Carrier frequency (f_c) = 100 GHz

Sl	Distance (d)	Q-Factor	BER	Eye Height	Threshold
1	100 Km	38.75	0	0.1133	0.0078
2	150 Km	9.31	6.125×10^{-21}	0.0082	0.0063
3	200 Km	2.91	0.0015	-3.84×10^{-5}	0.0010
4	250 Km	2.20	0.0097	-4.42×10^{-5}	0.0002
5	300 Km	0	1	0	0



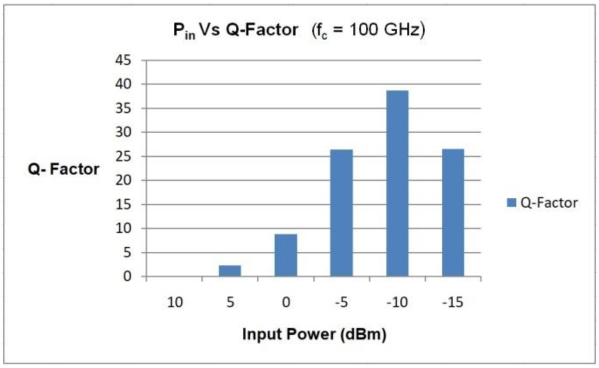


Fig. 4(a) Variation of Input Power (P_{in}) Vs Q- factor at Fig. 4(b) Variation of Input Power (P_{in}) Vs Q- factor at Carrier Frequency (f_c) = 50 GHz. Carrier Frequency (f_c) = 100 GHz.

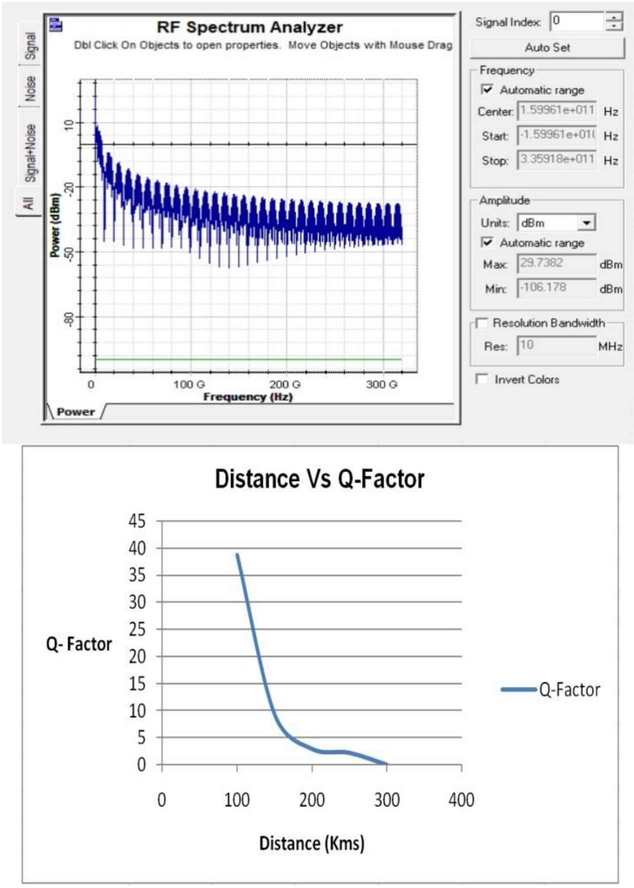


Fig. 5(a) Variation of Input Power (P_{in}) Vs Frequency (Hz) Fig. 5(b) Variation of Distance (Km) Vs Q-factor

channel characteristics is required for error free transmission. The variation of Distance (Km) Vs Q-factor is as shown in Fig. 5(b). It is clearly seen form the eye diagrams that by the inclusion of AOF and FBG in our design, the impact of nonlinearities and dispersion has been minimized. Wider and clear is the opening of the eye diagram, better is the quality of the signal received at the receiver. Further, from the numerical analysis, it is clear that a Carrier frequency of 100 GHz offers better performance compared to a carrier frequency of 50 GHZ.

5. Conclusion

The simulation of an Optical fiber transmission system without and with AOF along with FBG Dispersion compensator is done using Optisystem 19.0. With the use of AOF and FBG Dispersion compensator, the results showed a low BER of 3.075×10^{-168} and high Q-factor of 27.61 with an Eye height of 0.118 which is found to better than the other configuration. Further the Receiver showed optimum performance for an Input power of
P_{in} = -10 dBm and Carrier frequency of 100 GHz.

The maximum Q-factor that was measured is 38.75, minimum BER being zero, Eye height of 0.1133 and Threshold being 0.0078 for a distance of 100 Km. The NRZ pulse generator is used since it is much tolerant to various nonlinearities and dispersion. The EDFA amplifier provides better amplification and low noise which is suitable for long distance transmission. Low BER, high Q factor and better Eye height is obtained for the combination of AOF and FBG Dispersion compensator.

References

[1] Singh S, Kumar S, Payal. Radio over fiber communication system: lateral shift in cellular communication. Int J Emerg Technol. (2020) 11:731–4.
[2] Kumar S, Sharma D, Payal, Singh R. Performance analysis of radio over fiber link using mzm external modulator. In: Luhach A, Kosa J, Poonia R, Gao XZ, Singh D, editors. First International Conference on Sustainable Technologies for Computational Intelligence (ICTSCI-2019). Singapore: Springer; ASIC (2020). doi: 10.1007/978-981-15-0029-9_18
[3] Ahlawat D, Arora P, Kumar S. Performance evaluation of proposed WDM optical link using EDFA and FBG combination. J Opt Commun. (2021) 40:101–7. doi: 10.1515/joc-2018-0044
[4] Kathpal N, Garg AK. Analysis of radio over fiber system for mitigating four-wave mixing effect. Digit Commun Netw. (2020) 6:115–22. doi: 0.1016/j.dcan.2019.01.003
[5] Dahiya S, Kumar S, Sharma D, Arora P. Mitigating polarization mode dispersion for enhanced capacity in polarization division multiplexed (PDMQAM) optical fiber communication link using Processing XIV 115090L. San Diego, CA (2020). doi: 10.1117/12.2566904
[6] Payal, Kumar S. Nonlinear impairments in fiber optic communication systems: analytical review. In: Futuristic Trends in Network and Communication Engineering (FTNCT-2018), Chapter-3, Vol. 958. Singapore: Springer; CCIS (2019). p. 28–44.
[7] Soni A, Pradesh M, Prajapati N, Sharma N. A review article of WDM based optical fiber communication withWDMsystem evolution. Int J Adv Res Ideas Innovat Technol. (2018) 4:739–43.
[8] Nain A, Kumar S. Performance investigation of different modulation schemes in RoF systems under the influence of self phase modulation. J Opt Commun. (2018) 39:343–7. doi: 10.1515/joc-2016-0155
[9] Amari A, Dobre OA, Venkatesan R, Kumar OS, Ciblat P, Jaouën Y. A survey on fiber nonlinearity compensation for 400 Gb/s and beyond optical communication systems. IEEE Commun Surv Tutor. (2017) 19:3097–113. doi: 10.1109/COMST.2017.2719958
[10] Nain A, Kumar S, Singla S. Impact of XPM crosstalk on SCM-based RoF systems. J Opt Commun. (2017) 3:319–24. doi: 10.1515/joc-2016-0045