

Design and Comparison of Traditional and Optimized DM Soliton transmission systems at 100 Gbps

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Abstract: In this paper the dispersion managed (DM) soliton transmission system is first of all optimized according to the needs of a user following which its performance is compared with traditional optical soliton transmission system. The design, implementation and performance comparison of both the systems is performed at a bit rate of 100 Gbps. Under the same operating conditions, the possible faithful transmission distance is calculated of the respective systems is calculated keeping Q factor and BER to be same. This paper gives the detailed analysis of performed simulation, numerically choosing the proper design of dispersion map for dispersion managed systems. It will be seen that the DM soliton transmission systems outperform the traditional systems be it the transmission distance, Q factor or BER comparison. The DM soliton transmission systems are optimized based on the proper choice of map strength, average group velocity dispersion and lengths of single mode fiber (SMF) & dispersion compensating fiber (DCF) respectively. The simulation when carried for same Q factor ~6 & BER ~ 10^{-9} thus shows that dispersion managed systems are able to achieve far longer transmission distance than that possible to achieve from traditional soliton transmission systems.

Keywords: DM Solitons, traditional optical solitons, SMF, DCF, GVD, Q factor, BER.

I. INTRODUCTION

Single mode fiber (SMF) is a mean of achieving long distance fiber optic communication, as a result these systems have to deal with the problem of chromatic dispersion. Optical solitons are one of the solution that experience dispersionless pulse propagation over long distances because of a balance between group velocity dispersion (GVD) and the nonlinearity effect called self phase modulation (SPM) [1]. However, in order to preserve the soliton pulse shape over long distances, GVD parameter is required to be kept constant. Using dispersion compensated fiber (DCF) along with SMF with proper choice of dispersion map makes it possible to achieve the lossless soliton all over the transmission distance. These solitons are termed as dispersion managed (DM) solitons [2-4]. In this paper, the numerical analysis of dispersion map design for DM Soliton transmission system and the proposed simulation setup for pulse propagation in Traditional and Dispersion Managed systems has been presented which is performed under the same operating conditions. This allows a direct and fair performance comparison of these two types of optical soliton transmission systems. Here, the simulation is performed where BER of 10^{-9} ensures faithful transmission. The possible faithful transmission distance is thus calculated keeping BER to be $\sim 10^{-9}$ and Q factor to be ~ 6 in both the transmission systems.

II. DISPERSION MAP DESIGN FOR DM SOLITON TRANSMISSION SYSTEM

Map strength (S) and average GVD (β_2) are two important parameters on which the robustness of DM solitons depends [5]. It is necessary to use dispersion map in order to support the propagation of DM solitons at higher bit rates. As seen in Fig.1 it consists of many (n) DM periods (z_p) within one amplifier span (z_a) [6-8]. In order to keep the pulse breathing with minimum interactions, the length of DM period in a dispersion map have to be chosen carefully while keeping the local dispersion high enough so as to suppress the four wave mixing impairments.

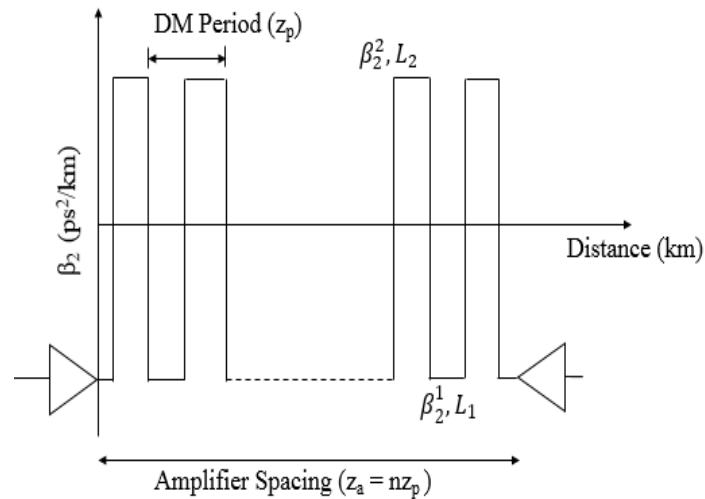


Fig.1 Densely Dispersion Managed System

Map strength is a significant parameter which affects the propagation dynamics of DM solitons and is taken to be $S=1.65$ here [9]. Taking 100 Gb/s [10] DM system operating at 1550nm, in order to reduce the soliton interaction i.e. to minimize the effect of attraction and repulsion and increase transmission performance, the required pulse width is 3 ps.

III. SIMULATION SETUP OF PROPOSED WORK

A. Dispersion Managed Soliton Transmission System

The soliton pulses are generated by using the Mode locked laser. These soliton pulses are passed through dispersion map through which they acquire the characteristics of DM solitons. As the propagation of DM solitons is at high bit rate, a dense dispersion map is chosen. The unit cell of the DDM consists of High nonlinear fiber (HNLf), Dispersion compensating fiber (DCF) where length of each segment is 3.1 Km. The unit cell is repeated through a loop for 8 iterations, and the amplifier setup (containing EDFA) is placed after 2 such unit cells so that amplifier spacing is about 99.2 km [7]. An optical band-pass filter is placed after EDFA to enable frequency selective feedback (FSF).

The simulation set up used for transmission of DM soliton pulses at 100 Gbps is shown in Fig. 2. The generated soliton pulses are transmitted in an optical link. The optical link consists of dispersion map (6.2 Km) periodically placed in the optical link. The amplifier spacing is taken as 49.6 Km (50 Km approximately). The propagation distance is increased by passing the DM soliton pulses in a recirculating fiber loop. This recirculating fiber loop consists of a dispersion management section containing loops of dispersion map and frequency selective feedback in which 4 dense dispersion maps are used. One dense dispersion map consists of 8 unit cells (at 100 Gbps) i.e. the loop of one unit cell is repeated 8 times. The length of whole dispersion map then becomes, 198.4 Km as 4 dense dispersion maps are used. Other typical parameters of SMF are Loss = 0.2 dB/km, $n_1 = 1.4682$ and effective core area $A_{eff} = 90 \mu m^2$.

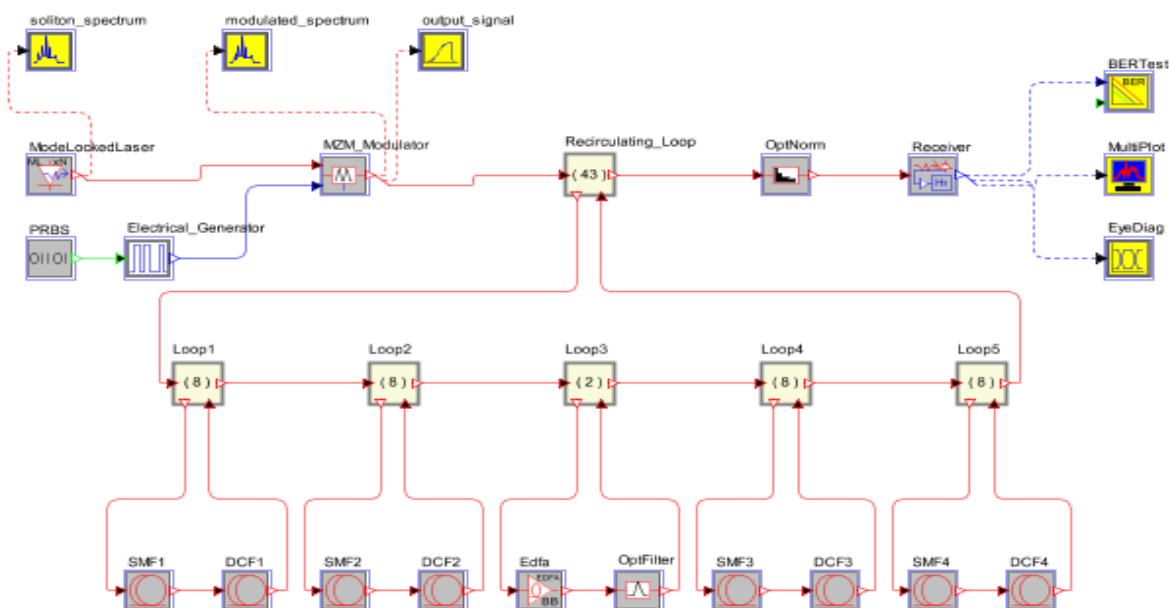


Fig. 2 Simplified model of DM Soliton transmission system simulation set-up

The propagation distance is thus increased in steps of the 198.4 km and performance of the pulses is analyzed at the receiver. Ideally, optical filter should be placed after every amplifier in the optical link. But in this work, optical filters are placed in the transmission link after every 99.2 Km (≈ 100 Km i.e. 2 dispersion maps), so as to reduce the number of required components.

B. Traditional Optical Soliton Transmission System

The simulation setup used for transmission of traditional optical soliton pulses is shown in Fig. 3. These traditional optical soliton pulses are generated using Mode locked laser [3] and are made to pass through various sections of fiber loop. Every unit cell consists of single mode fiber (SMF), whose length is kept as 6.2 Km. The unit cell is repeated through a loop for 8 iterations, and the amplifier setup (containing EDFA) is placed after 2 such unit cells with an optical band-pass filter placed after every EDFA for the sake of comparison between the two systems i.e. the DM Soliton transmission system and the Traditional Optical Soliton transmission system.

The generated soliton pulses are transmitted in an optical link. The optical link consists of SMF (6.2 Km) periodically placed in the optical link. The amplifier is placed at a distance of 49.6 Km same as done in the DM Soliton transmission system mentioned above. The propagation distance is increased by passing the optical soliton pulses in a recirculating fiber loop.

The recirculating fiber loop consists of a section containing loops of fiber and frequency selective feedback in which 4 SMF loops are used. One SMF loop consists of 8 unit cells (at 100 Gbps) i.e. the loop of one unit cell is repeated 8 times, where length of each unit cell is 6.2 km which implies that one fiber loop length is equal to (49.6 Km ≈ 50 Km). The length of one recirculating loop then becomes, 198.4 Km as 4 fiber loops are used. The propagation distance is thus increased in steps of the 198.4 km and performance of the pulses is analyzed at the receiver as is done in the case of DM Soliton transmission system. One unit cell consists of a span of 8 number of loops where each unit cell (loop) is made up of single section of fiber of 6.2 km length: a single mode fiber (SMF) with group velocity dispersion β_2^1 [8].

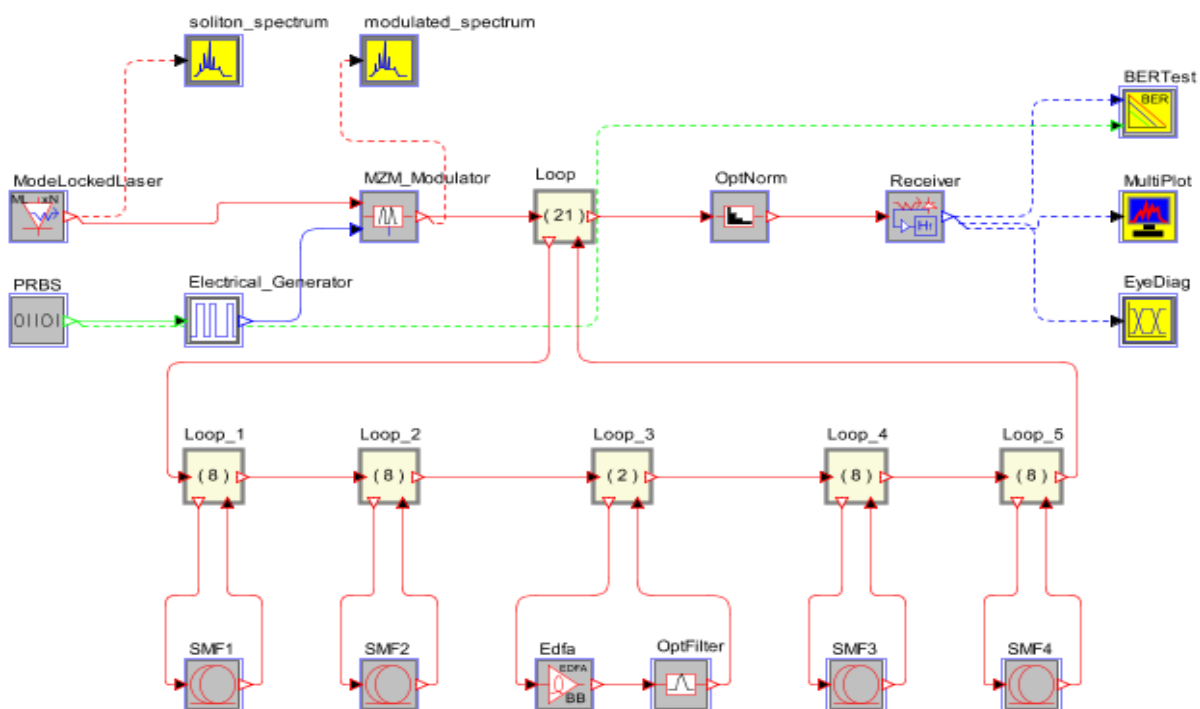


Fig. 3 Simplified model of Traditional Optical Soliton transmission system simulation setup

It is found that for the quality factor $Q \sim 6$ and $BER \sim 10^{-9}$, a 4166.4 km of optical reach is possible to be obtained for the bit rate of 100 Gb/s at a wavelength of 1550nm with laser's power of 2mW and pulse width of 3 ps.

IV. SIMULATION RESULTS

A. Optimization of DM Soliton transmission system

1. *Influence of Average Group Velocity Dispersion:* As seen in Fig.4 and Table 1 for a particular value of map strength the increase in average GVD (β_2) of a fiber leads to a reduction in the optical reach with maximum optical reach obtained for $\beta_2 = 0.1$ when compared to that of 0.3 and 0.6. It can also be seen from the plots showing variation in Q factor in Figure 4 that for every value of map strength, maximum Q factor is got for $\beta_2 = 0.1$. Thus, showing that to achieve a faithful transmission over long distance, a fiber of low average dispersion parameter must be chosen.

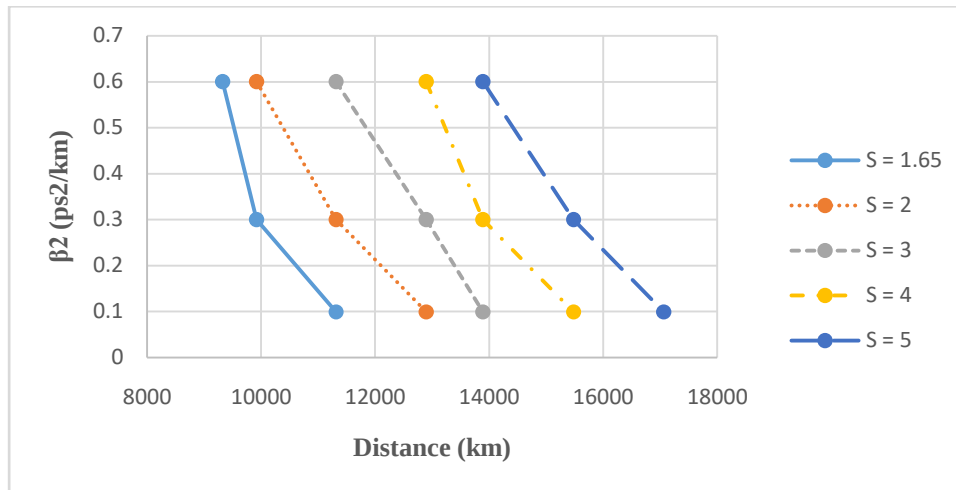


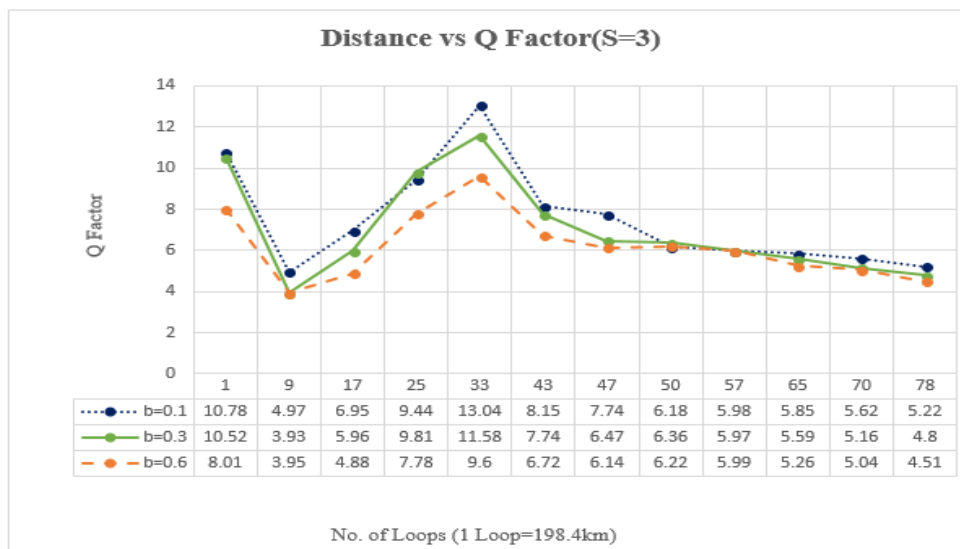
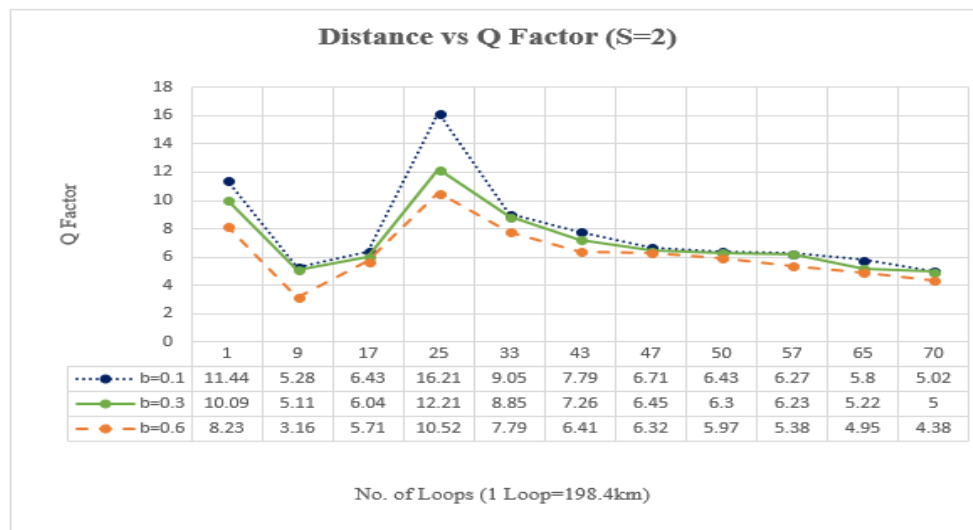
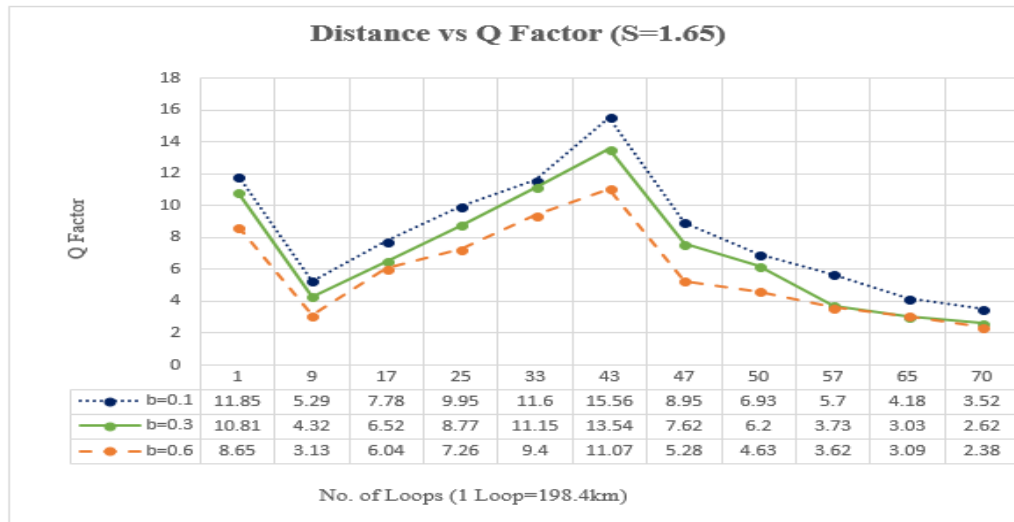
Fig. 4 Variation in Distance (km) with changes in Average GVD (β_2) and Map strength (S) in DM Soliton transmission system

TABLE I

ACHIEVED TRANSMISSION DISTANCE (KM), FOR PARTICULAR VALUES OF MAP STRENGTH, SMF AND DCF LENGTHS

Map Strength (S)	β_2 (ps ² /km)	Distance (km)
1.65	0.1	11308.8
	0.3	9920
	0.6	9324.8
2	0.1	12896
	0.3	11308.8
	0.6	9920
3	0.1	13888
	0.3	12896
	0.6	11308.8
4	0.1	15475.2
	0.3	13888
	0.6	12896
5	0.1	17062.4
	0.3	15475.2
	0.6	13888

2. *Influence of Map strength:* TableI clearly shows the effect of map strength on the possible faithful transmission distance. It can be seen that the increase in S shows an increase in the possible transmission distance with maximum distance of 17062.4 km obtained for S=5. However, the variation of Q factor in Fig.5 shows the successive reduction in the maximum Q factor obtained with an increase in map strength. Thus, if the accuracy is of prime importance then a system with lower map strength can be chosen and if accuracy is not an issue then higher map strength can be used for achieving longer transmission distance. The dispersion managed system can thus be optimized according to the needs of the user.



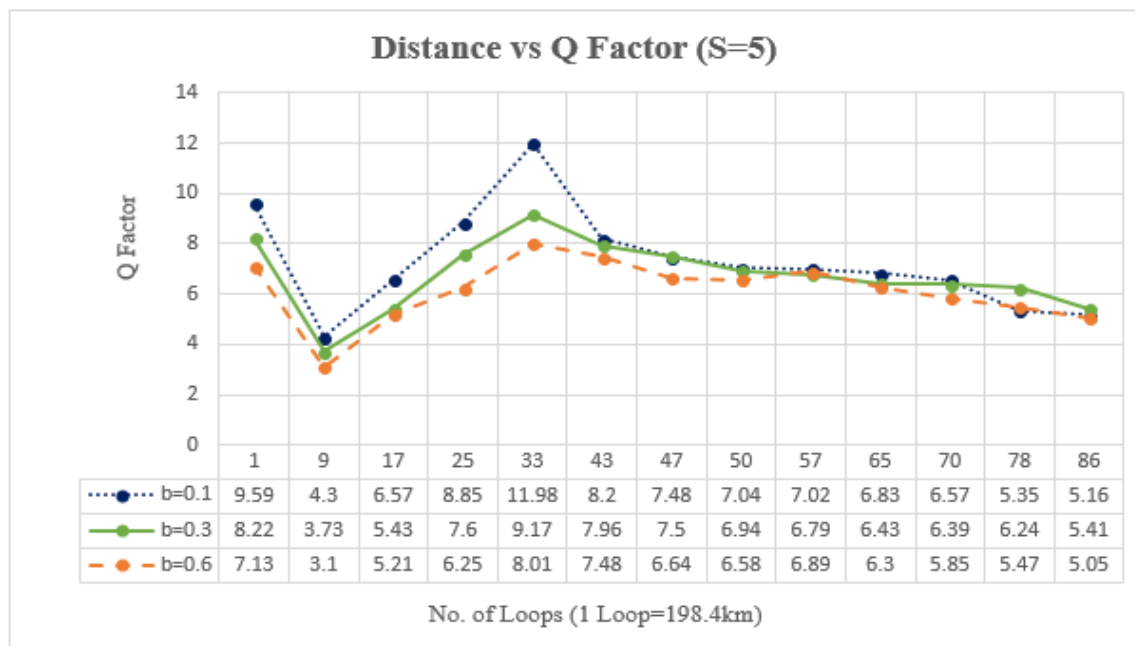
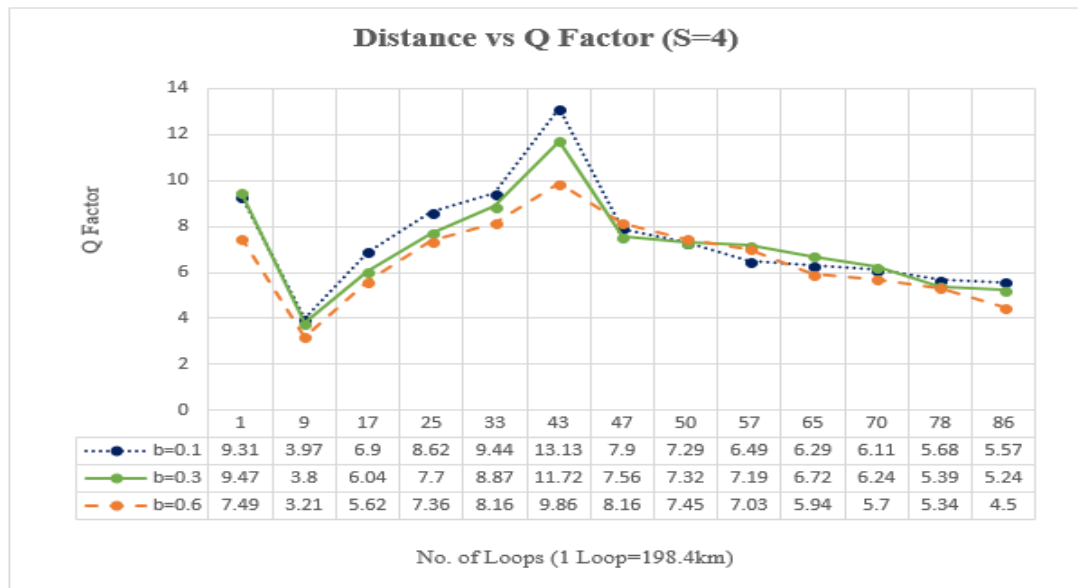


Fig.5 Q factor variation with number of loops (Distance,km) for different average GVD ($\beta_2=0.1, 0.3 \text{ \& } 0.6 \text{ ps}^2/\text{km}$) respectively for a given value of S (1.65,2,3,4,5) in a DM Soliton transmission system.

3. *Influence of Lengths of SMF and DCF:* Up till now the analysis was done for equal lengths of SMF and DCF with $L_{SMF}=L_{DCF}=3.1 \text{ km}$. But here the simulation is carried out for different lengths of fiber where the value of S is changed based on change in length. For a particular value of map strength and feasible lengths of SMF and DCF, the faithful possible distance of transmission is calculated. For a particular value of map strength two set of values are taken for the length of fibers and it is observed that longer transmission distance is achieved when L_{SMF} approaches L_{DCF} with further increase in the faithful transmission distance for the corresponding increase in map strength. The variation of Q factor with transmission distance has been shown in Fig.6below.

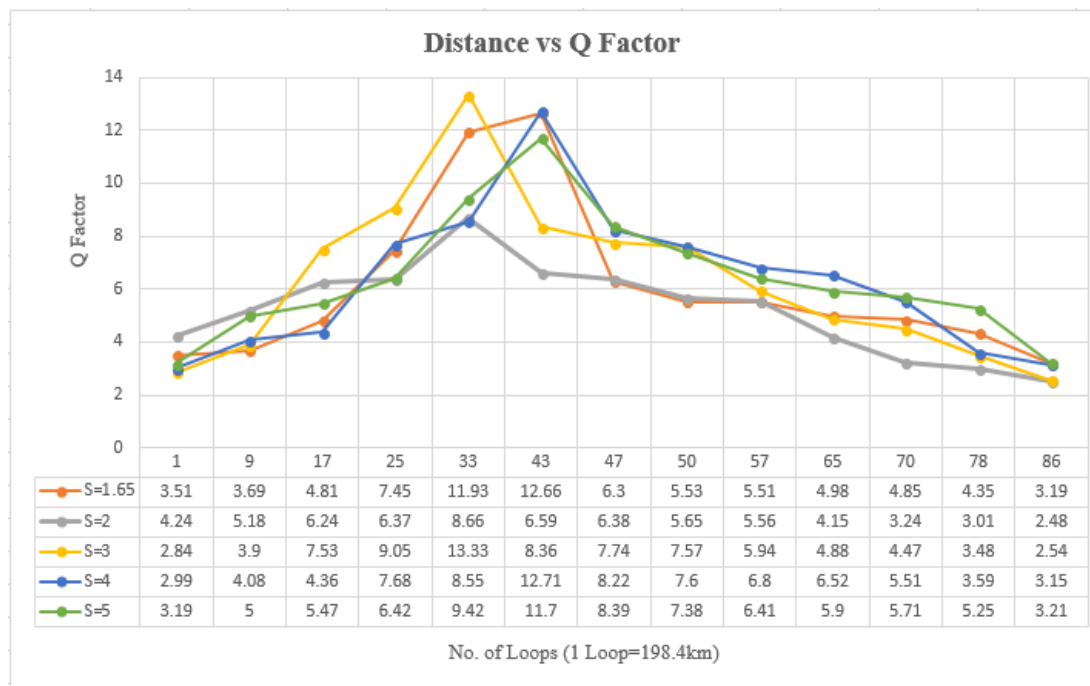
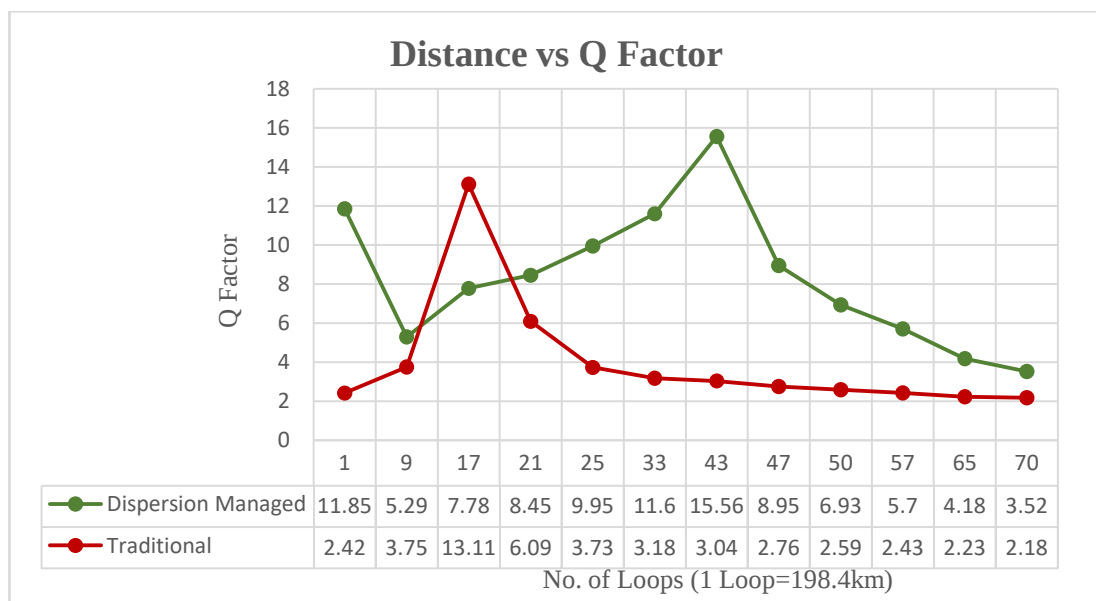


Fig. 6 Variation of Q factor with number of loops (Distance, km) for $S=1.65, 2, 3, 4$ & 5 resp. taking different SMF and DCF lengths for a fixed $\beta_2=0.1 \text{ ps}^2/\text{km}$ in a DM Soliton transmission system.

B. Comparative study of optimized Dispersion Managed and Traditional Optical Soliton Transmission Systems

The performance comparison of both traditional and dispersion managed optical soliton systems was done in terms of quality factor and BER. The variation of Q and BER with number of loops is shown in Fig.7. Each loop consists of 6.2 km of fiber length with traditional optical soliton transmission system containing only SMF of length 6.2 km and DM soliton transmission system containing both SMF and DCF of lengths 3.1 km each making each loop containing fiber length of 6.2 km as in the case of traditional system for the fair comparison of both the systems respectively.



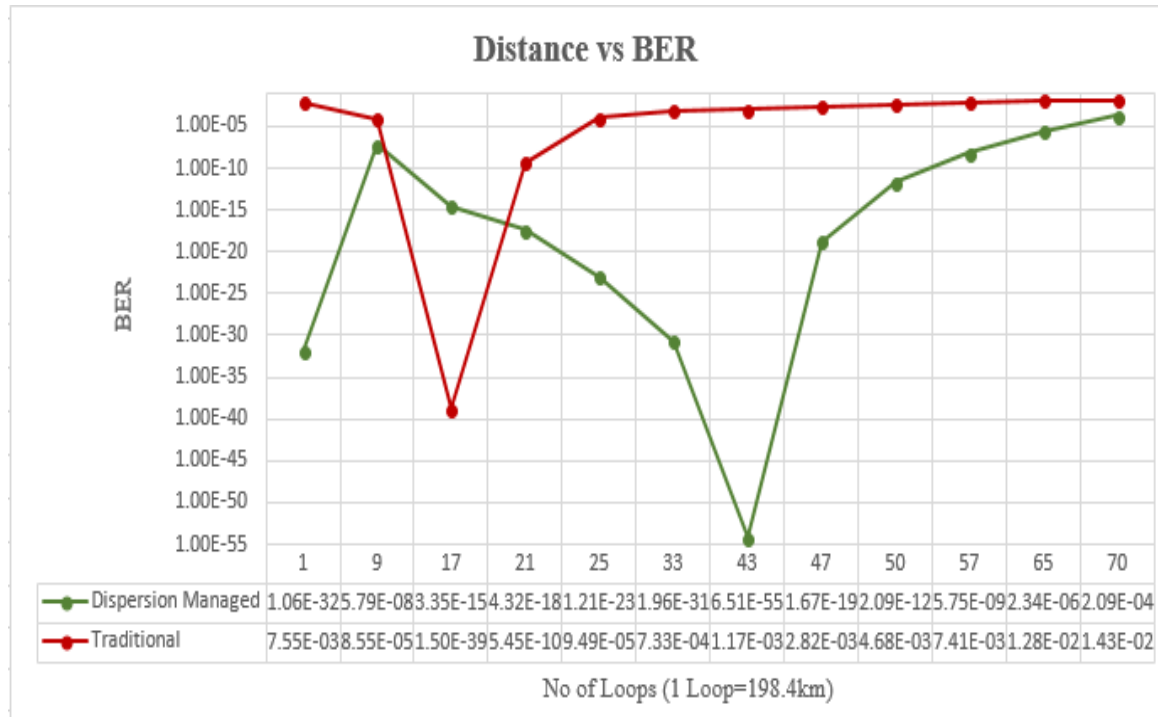


Fig.7 Q factor and BER variation with number of loops (distance, km) in Traditional and DM Soliton transmission systems

Where the BER of 10^{-9} and Q factor of 6 is achieved for an optical reach of 4166.4 km in case of traditional soliton transmission system there the maximum optical reach of 11308.8 km ($\beta_2 = 0.1 \text{ ps}^2/\text{km}$) is possible to be obtained in dispersion managed soliton transmission system at 100 Gbps. Hence, these are able to propagate faithfully over long distances making a vast difference in the respective possible faithful transmission distance of both the systems.

V. CONCLUSION

After comparing all the results it has been analysed that using dispersion compensating fiber along with proper choice of dispersion map leads to a huge increase in the distance up till which the faithful transmission is possible. Thus ensuring dispersion managed soliton transmission system to be the best system for data transfer in a soliton fiber link. Using appropriate type of optical fibers i.e. SMF and DCF (of appropriate GVD coefficients), best results of the transmission distance can be obtained in an optimized DM Soliton transmission system. Here, the DM Soliton transmission system having average GVD of 0.1 provided the longest optical reach of 11308.8 km at $S=1.65$. Thus, propagating in the same operating conditions dispersion managed systems show a much more increase in transmission distance than the traditional soliton transmission system.

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