Dispersion effect on Single mode Optical fibre transmission link

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Abstract — *Fibre Optics is one of the best transmission technologies in the recent years; however, dispersion limits its transmission distances. This paper presents effects of dispersion in optical links and demonstrates how dispersion compensation fibre (DCF) is used to compensate for the effect of dispersion in a single mode fibre transmission link. Two scenarios were demonstrated using Optisystem simulation tool; a transmission network without a DCF and another with DCF. Results showed that network without DCF was greatly affected by dispersion. The bit error ratio (BER) analysers showed high bit error ratio and very low quality factor (Q factor). This depicts that the pulses were spreading out in time as it propagates down the fibre due to dispersion. In the second scenario, DCFs were introduced in the network based on designed specifications and results showed that BER at each receiver was very low and some to the tone of e-25. Q factor obtained was high enough. The results reveal that with DCF, the effect of dispersion in single mode fibre is compensated for.*

Keywords — *Dispersion, DCF, SMF,Q-Factor, BER, Fibre Optics.*

I. INTRODUCTION

Communication has taken a new swift with advent of fourth generation (4G) and fifth generation (5G) of mobile communication networks. This has resulted to very high speed internet connectivity, machine to machine communication, high data applications, internet of things (IoT), online gaming and a lot more. The new generation applications on most mobile devices are bandwidth hungry resulting to huge traffics. To backhaul these huge traffics, fibre optics is seen to be one of the best technologies because of its excellent technical attributes like unlimited capacity, range and reliability [1]. Another desirable feature of optical fibre is the ability to process information entirely for the purpose of amplification, multiplexing, de-multiplexing, switching since optical signal processing is more efficient than electrical signal processing [2].

Fibre optics is a thing flexible but transparent material that uses glass (or plastic) to transmit data, it acts as a ‘light pipe” to transmit light between two ends of the fibre. Despite fibre optics’ excellent attributes, some factors like attenuation and dispersion tend to limit power budget and link distances respectively. This paper discusses the effects of dispersion on a single mode fibre (SMF) link. Dispersion in optics means the spreading out of a light pulse in time as it propagates down the fibre. According to [3], dispersion is generally classified into Chromatic (material) and Intermodal (multipath) dispersions. In chromatic dispersion, pulse of light entering a fibre contains a range of wavelengths that travels at different speeds. Some wavelengths will inevitably reach the end of the fibre before others, hence causing the pulse to spread out of time. Chromatic dispersion is the dominant source of dispersion in single mode fibres (SMF) and also in multimode fibre systems using optical sources with a broad linewidth (eg LEDs). Intermodal dispersion in the other hand is the spreading due to different rays of light taking different paths down a multimode fibre, therefore, some rays take longer to reach the end than others and a pulse of light spreads out in time. In single mode fibre, Dispersion compensation fibre (DCF) is a fibre specially designed to have a large dispersion with opposite dispersion characteristics to main transmission fibre. It is used to compensate for the effects of dispersion in single mode fibre.

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II. METHODOLOGY

For a better understanding of this research, a fibre link with the parameters as shown in table 1 is considered.

To carry out the design based on the parameters on table 1, consider figure 1 as the block diagram representing the design. Figure 1 is made up three (3) segments: transmitter, channel and the receiver. The transmitter has a transmit power of -2dBm, the channel is a single mode fibre of distance 320km and the receiver has a receiver sensitivity of -28dBm.

TABLE 1- DESIGN PARAMETERS

Link Parameter	Units
End to end capacity	100Gbit/s
End to end distance	320km

Transmitter power	-2dBm
Receiver sensitivity	-28dBm
Spectral line width	0.1nm
Min BER at the receiver	E-09
SMF Parameter	**Units**
Attenuation of SMF at 1560	0.27dB/Km
Chromatic dispersion coefficient	16.34ps/km.nm
Splice and connector loss	0.07dB/km
System Margin	6M
DCF Parameter	**Units**
Chromatic dispersion coefficient	-80ps/km.nm
Attenuation	0.55dB/km
Amplifier	20dB gain

A. Calculation for dispersion

Since it is a SMF, only Chromatic Dispersion is considered

Chromatic Dispersion = $DL\Delta\lambda$……………….........(1)

Where D = Dispersion coefficient = 16.34ps/km.nm

L = Length of the Fibre = 320km

$\Delta\lambda$ = Transmitter line width = 0.1nm

Chromatic Dispersion = 16.34ps/km.nm x 320km x 0.1nm = 522.88ps ………………………………...(2)

To get the length of Dispersion Compensation Fibre (DCF) needed to compensate the Chromatic Dispersion, the Chromatic Dispersion of SMF and that of DCF is made equal.

Hence,

Chromatic Dispersion of SMF = Chromatic Dispersion of DCF

From equation 2,

Chromatic Dispersion of SMF = 522.88ps

Chromatic Dispersion of DCF is given by $DL\Delta\lambda$... (3)

Where D = Dispersion coefficient = -80ps/km.nm

L = Length of the Fibre = Unknown

$\Delta\lambda$ = Transmitter line width = 0.1nm

Therefore;

522.88ps =-80ps/km.nm x L x 0.1nm …..(4)

L = 522.88ps / -80ps/km.nm x0.1nm

= - 65.36km (the –ve sign shows it is a compensating length)

If the 65.36km length of the DCF is added to figure 1, the network diagram is as seen in figure 2.

B. Power Budget Analysis

This considers the attenuation and losses in the fibre link to ensure there is sufficient power to detect the signal at the receiver. Figure 3 shows the network diagram with losses

Where αf = the fibre attenuation,

αs = Splice losses and αc = connector losses

M = System Margin

Po = Transmitter output power.

Pi = Receiver Sensitivity, Power needed at the receiver to give a min BER of 10 E-09

The total losses in the system is obtained from

Po – Pi = (Loss of SMF + Loss of DCF + System Margin M)……………………………..(5)

Loss of SMF = L x loss = 320km x {splice and connector losses + fibre attenuation}……………..(6)

= 320 x {0.07+ 0.27} = 320 x 0.34 =108.8dB

Loss of DCF = Length of the DCF x loss = 65.36 x {splice and connector loss + DCF attenuation}………………………(7)

= 65.36 x {0.55+ 0.07} = 65.36 x 0.62 = 40.52dB

System Margin M is given as 6dB

Therefore,

Po – Pi = (108.8 + 40.52 + 6) = 155.32dB = Total loss in the system.

But Po – Pi = -2 – (-28) = -2 + 28 = 26dB,

The loss is more than the power; hence the signal will not get to the receiver.

An amplifier of 20dB gain will be used. To know the number of this 20dB gain amplifiers that will be used, equation 8 is considered;

155.32dB - 26dB = 20dB x n …………………(8)

Where n = number of 20dB gain amplifier needed in the system.

129.32/20 = 6.466 = n

But n must be a whole number, therefore, n is approximated to 7. Hence, 7 numbers of 20dB gain amplifier will be used.

To find the distance on a SMF where its loss will be equal to gain of the 20dB gain amplifier, consider equation 9;

20dB = L (km) x 0.34dB………………………(9)

Where L = length of the SMF where its loss is equal to 20dB gain of amplifier

0.34dB = SMF attenuation + splice and connector losses (as shown in equation 6)

20dB/ 0.34dB = L = 58.82km

For DCF,

20dB = L (km) x 0.62dB ……………………(10)

Where L = length of the DCF where its loss is equal to 20dB gain of amplifier

0.62 = DCF attenuation + splice and connector losses (as shown in equation 7)

20dB/0.62dB = L = 32.26km.

Figure 4 shows the network diagram containing SMF, DCF and amplifiers. From transmitter to the first amplifier is 58.82km, that's the length at which the loss in the system is equal to 20dB gain amplifier. It is repeated until the 320km length is exhausted. It is the portion described as the SMF while DCF is the lengths used in compensating for dispersion.

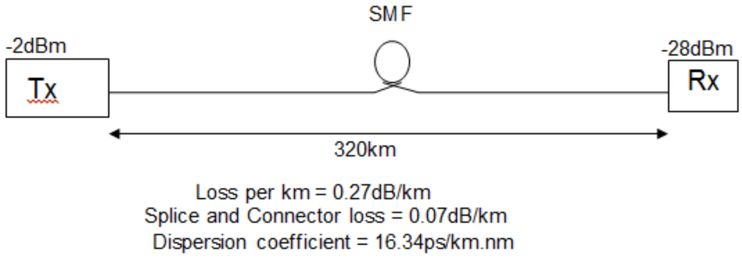

Fig 1: Block diagram for the link

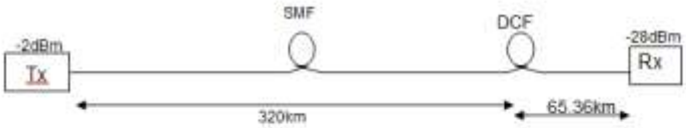

Figure 2: Network Diagram with DCF

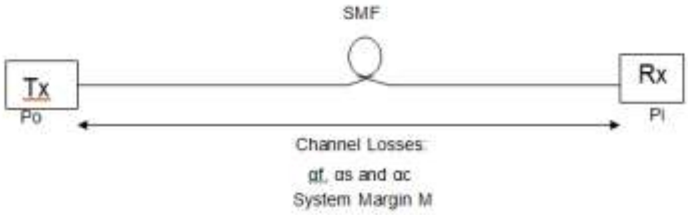

Figure 3: Block diagram with Losses

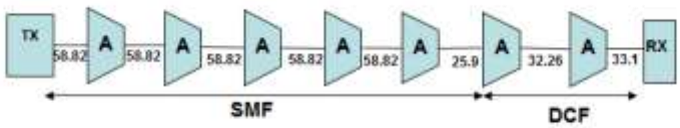

Figure 4: Network Block diagram with 7 amplifiers in their position

32.26km is the length of the DCF at which the loss is equal to 20dB gain and it continued till the whole compensating lengths is also exhausted.

III. OPTICAL SIMULATION

The simulation was carried out in Optisystem environment and was done in two phases: Phase one was done without DCF while in phase two, DCFs were added. The following optisystem devices were used; Transmitter, WDM, Fibre, and Receiver. The results were compared to check the effects of dispersion in the system.

A. Transmitter Section

Figure 5 shows the block diagram of the transmitter section, it is made up of Pseudo Random bit sequence (PRBS) generator, non-return –to zero (NRZ) generator and a modulator. The output of the modulator is an optical signal. The Pseudo Random Bit sequence (PRBS) generator generates bit streams of binary pulses of 0s and 1s of a known binary pattern. The output of PRBS goes to the NRZ generator. The NRZ generator creates a sequence of non-return –to zero pulses coded by input digital signal, hence shapes the input digital signal to a NRZ electrical signal. Another component of the transmitter is Continuous wave Laser that pumps light wave to M -Z modulator. The modulator has two inputs, one from the NZR pulse generator and the other from the CW laser. The modulator then transforms the Electrical signal to Optical signal. Since the designed link is 100Gbit/s, ten transmitter sections each of 10Gbit/s is used. WDM mux is used to multiplex all the signals from the ten transmitter sections into optic fibre cable. Figure 6 shows transmitter sections multiplexed using a WDM mux.

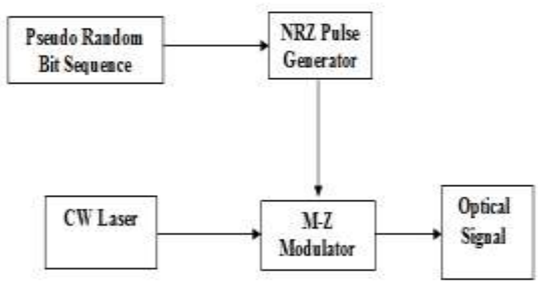

Figure 5: Network Block diagram of Transmitter section

The output of the WDM multiplexer links the channel, the channel in this case is single mode optical fibre. From equation 8, 7 numbers of 20 dB gain amplifiers were used to boast the optical signals. Phase one of the simulations was carried out without dispersion compensation fibres (DCF). Figure 7 shows a network without DCF. Red arrows in figure 7 shows point where DCF was not connected. Lengths of fibre and positions of amplifiers as directed by figure 4 were implemented in figure 7.

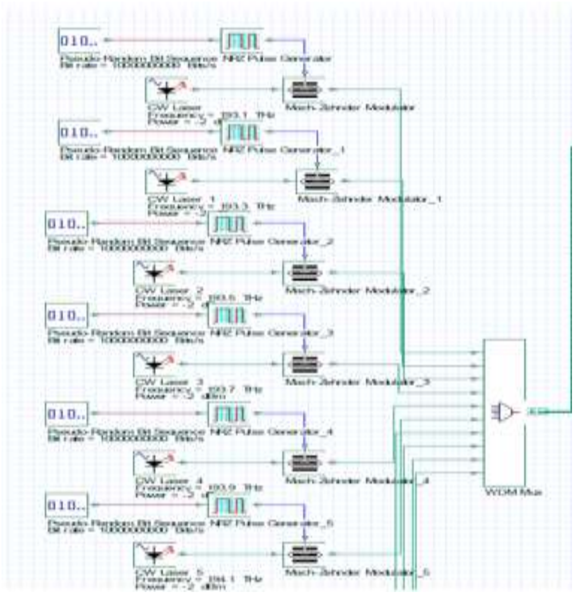

Figure 6: Transmitter sections with a WDM multiplexer

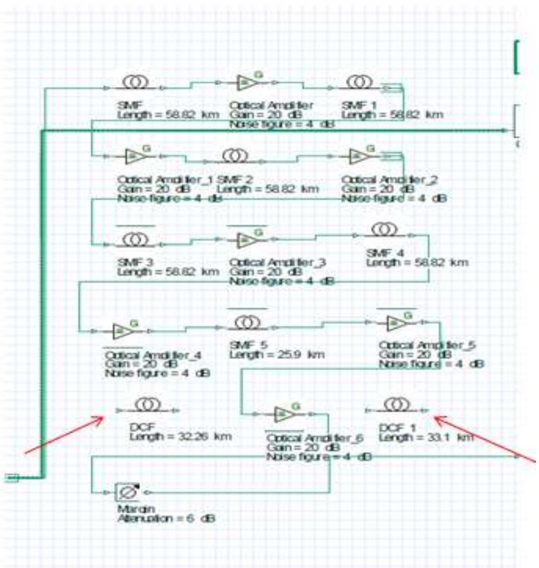

Figure 7: Network without DCF

B. Network without DCF

Complete network without DCF is shown in figure 8. The complete network diagram also shows the receiver sections. The receiver section is made up of filter, optical receiver and Bit error rate BER analyser.

The Bessel filter separates different frequencies associated with different wavelengths, each optical receiver has -28dBm power while the BER analyser displays the eye diagram and Q Factor among other things.

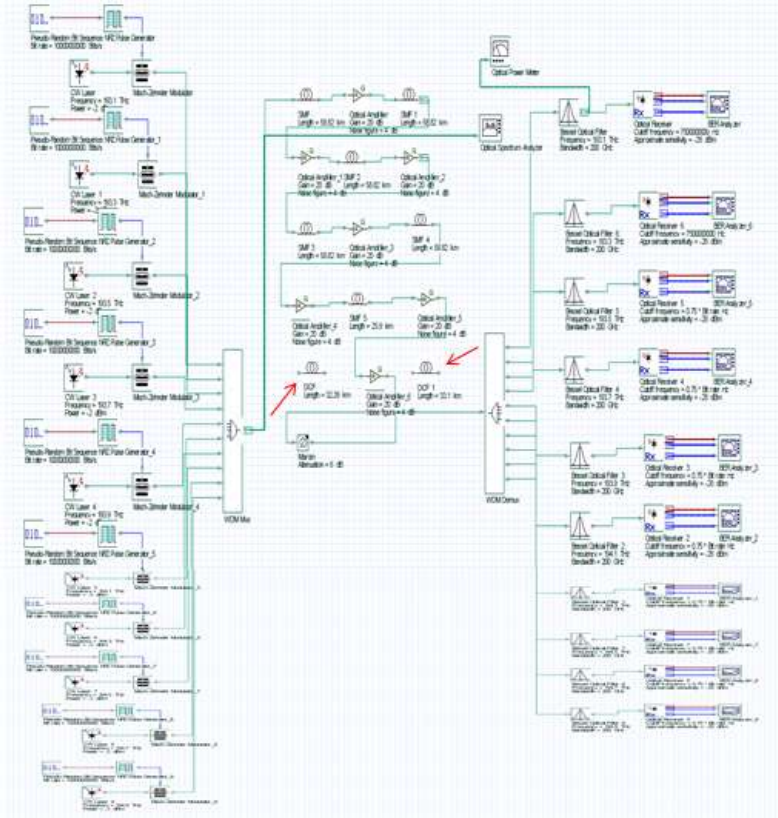

Figure 8: Complete Network without DCF

C. Network with DCF

In this network, DCF of lengths 32.26km and 33.1km as shown in figure 4 is implemented in the design shown in figure 9. The red arrows in figure 9 depicts where the DCFs were added in the network. Complete network with DCFs is shown in figure 10. The diagram shows the transmitter, channel and the receiver sections of complete network diagram with DCF of varying lengths.

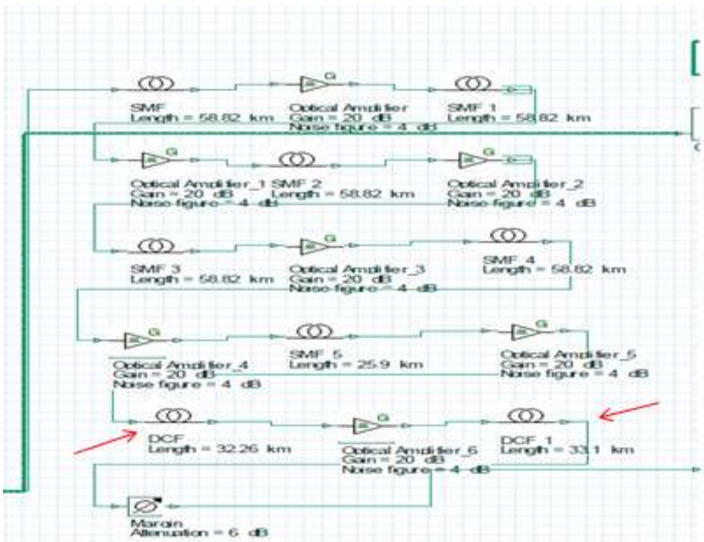

Figure 9: Network with DCF

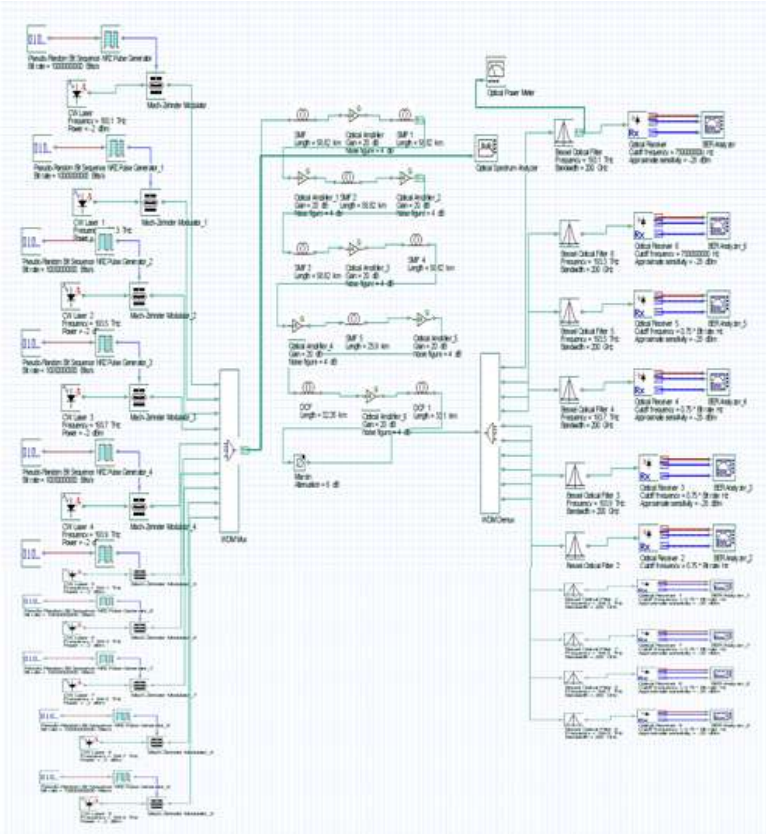

Figure 10: Complete Network with DCF

IV. RESULTS

The obtained results are in two variance, one is when the DCF was removed and the other when the DCF was connected. Figures 11(a and b) through 20 (a and b) shows the effects when DCF was removed and when it was connected for each case.

Figures 11a to 20a are when the DCF was removed, whereas, figures 11b to 20 b are when the DCF was connected. In Figure 11b, the minimum BER achieved was -25. This shows that the ratio of error per bit in the particular wavelength of the system is in the range of exponential -25. This is quite infinitesimal error ratio and hence portrays a good transmission link. The eye diagram of figure 11b has a shape of an eye typical of a good system. Conversely, figure 11a shows a minimum bit error ratio of 1. This demonstrates that the error per bit is one, meaning high level of error per bit in the particular wavelength of the system. Same analogy goes for figures 12a and b through figures 20a and b.

Quality factor (Q factor) measures the level of noise in a pulse, in other words, it provides a qualitative description of the receiver performance. The larger the values of Q factor, the freer the pulse (received signal) from noise, hence, the smaller the value obtained as BER. For figure 11 a, the BER is 1, meaning high error rate, the Q factor is zero. Figure 11b is when DCF was connected; it has a BER of 1.13e-25 and has a Q factor of 10.4

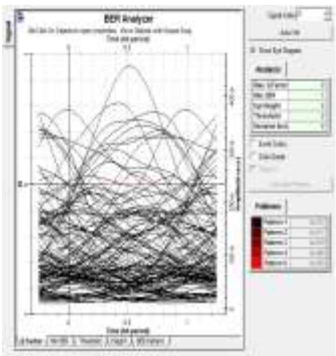

Figure 11 a: BER without DCF shows BER - 1

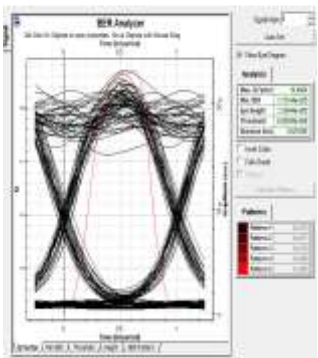

Figure 11 b: BER With DCF shows BER-15

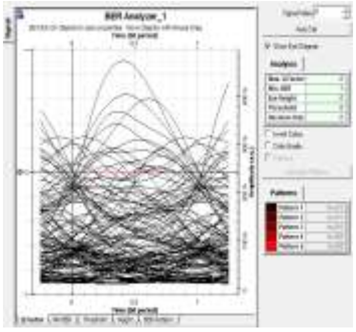

Figure 12 a: BER 1without DCF shows BER - 1

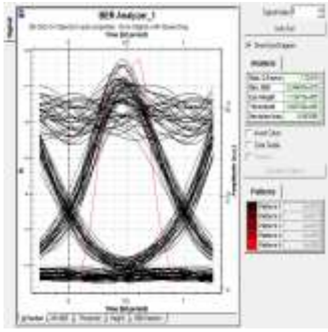

Figure 12 b: BER 1 With DCF shows BER-15

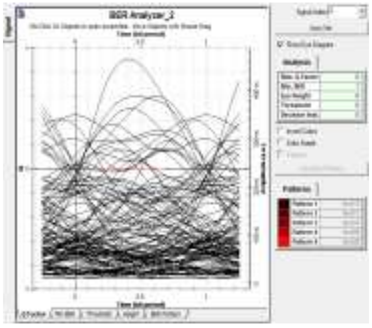

Figure 13 a: BER 2 without DCF shows BER – 1

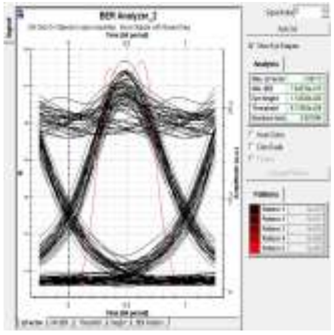

Figure 13 b: BER 2 With DCF shows BER-15

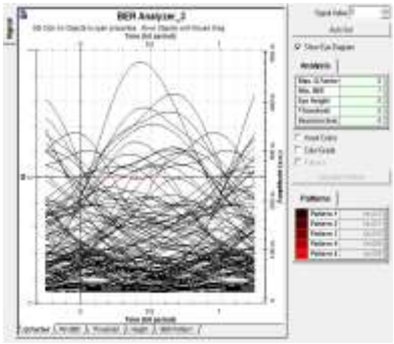

Figure 14 a: BER 3 without DCF shows BER - 1

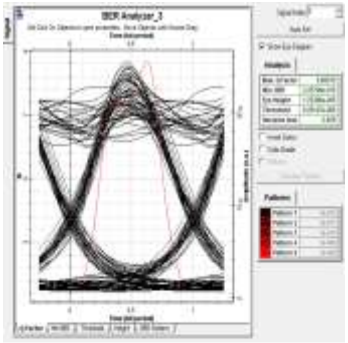

Figure 14 b: BER 3 With DCF shows BER-18

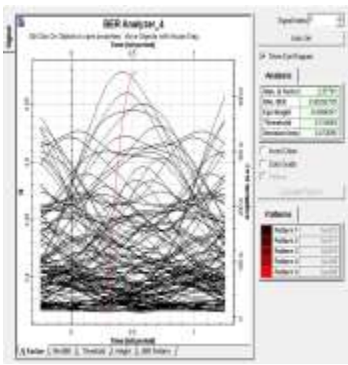

Figure 15 a: BER 4 without DCF shows BER 0.003

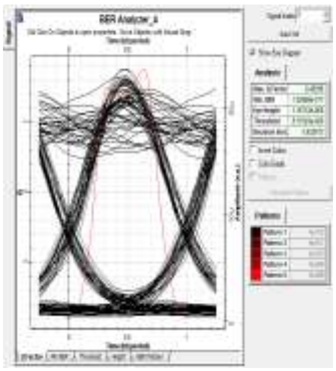

Figure 15 b: BER 4 With DCF shows BER-17

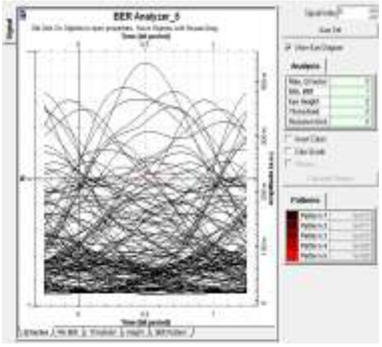
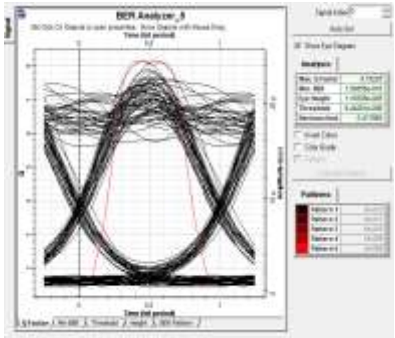

Figure 16 a: BER 5 without DCF shows BER 1 **Figure 16 b: BER 5 With DCF shows BER-16**

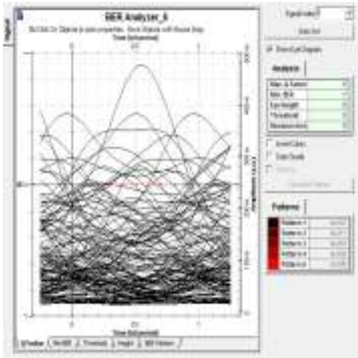
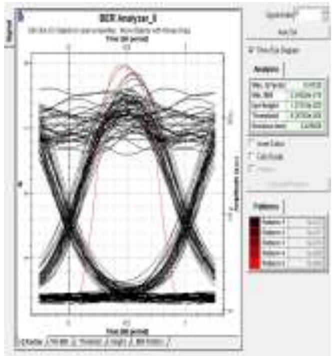

Figure 17 a: BER 6 without DCF shows BER 1 **Figure 17 b: BER 6 With DCF shows BER-19**

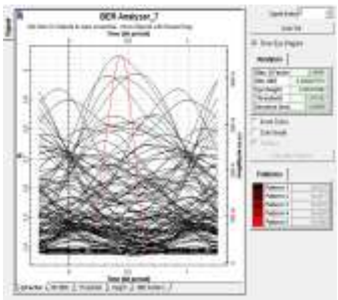
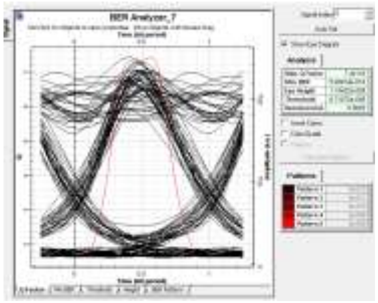

Figure 18 a: BER 7 without DCF shows BER 0.001 **Figure 18 b: BER 7 With DCF shows BER-14**

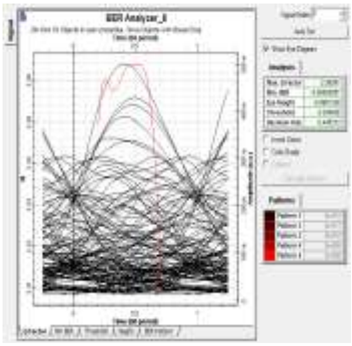
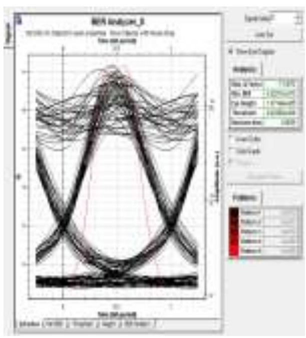

Figure 19 a: BER 8 without DCF shows BER 0.004 **Figure 19 b: BER 8 With DCF shows BER-13**

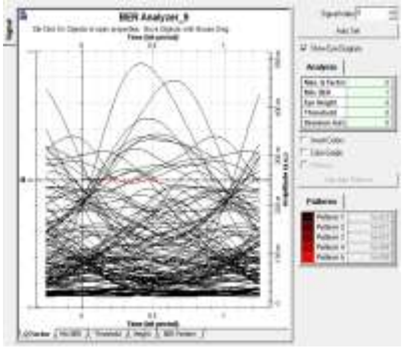

Figure 20 a: BER 9 without DCF shows BER 1

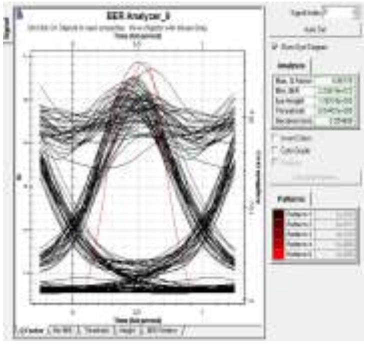

Figure 20 b: BER 9 With DCF shows BER-12

Table 2 shows the values obtained for ten BER anaylisers. The table shows the BER and Q factor values when DCF was connected and when it was removed. Figure 21 shows the pictorial presentation of figures obtained from simulation results depicted in table 2. When DCF was connected, the signal received has high Q factor for all the BER analysers. When DCF was removed, the Q factor values were minimal; bit error ratio for each BER was high meaning that the received signal has very high error per bit

TABLE 2 BER and Q Factor for Design with DCF and without DCF.

BER ANALYSERS	BER without DCF	Q Factor without DCF	BER with DCF	Q Factor with DCF
BER	1	0	1.13E -25	10.4
BER 1	1	0	5.30E-15	7.72
BER 2	1	0	7.60E-15	7.68
BER 3	1	0	2.56E-18	8.66
BER 4	0.003	2.57	1.02E-17	8.48
BER 5	1	0	1.55E-16	8.15
BER 6	1	0	2.04E-19	8.92
BER 7	0.001	3.05	5.47E-14	7.42
BER 8	0.004	2.36	4.32E-13	7.14
BER 9	1	0	3.24E-12	6.86

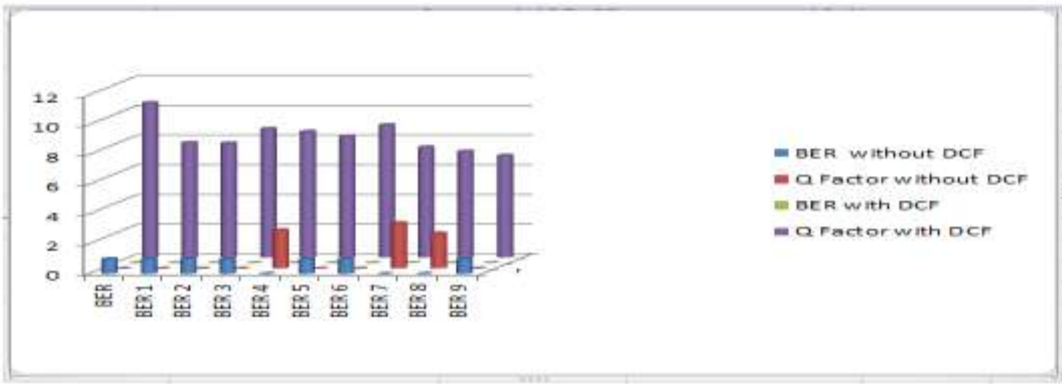

Figure 21: Pictorial representation of BER and Q factor values for with and without DCF

V. CONCLUSIONS

This research is concerned with demonstrating the effects of dispersion on a single mode optical fibre transmission link. The implementation was carried out in two scenarios; firstly, when the DCF was removed and when the DCF was connected.

Results obtained showed that when DCF was removed from the network, BER was very high on all the ten BER analysers used and Q factor was very low and even zero at some analysers. This means that the signals could not get to the receiver because of dispersion.

When DCF was connected, the highest BER obtained was exponential -12, best BER obtained was E-25. Q factor obtained was as high as 10.4. The result so obtained showed that the link with DCF has very low error per bit, hence a good transmission link.

With the findings stated above, it is obvious that pulse spreading limits transmission distances in optical fibre links and DCF is needed to compensate the effects of dispersion in a single mode transmission link.

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