

Dispersion Compensation Algorithm for Single Mode Fiber

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Abstract — Optical fibers enable the transmission of data through a long distance at very high speed and very low latency. However, this can be limited as a result of dispersion. This paper presents a dynamic MATLAB script that can mitigate against the dispersion in a single mode fiber (SMF) by calculating the length of dispersion compensation fiber (DCF) needed to offset the dispersion. It also calculates the number of amplifiers needed and the positions the amplifiers are to be placed. The results from the MATLAB script were also authenticated using Opti system. The average Bit error rate (BER) values gotten with simulation parameters of different scenarios shown in tables 1 and 2 are 7.6857×10^{-17} and 5.8036×10^{-10} respectively. The average Quality factor (Q-Factor) values of 10.046203 and 7.286533 were also gotten respectively. This showed that the effect of dispersion was compensated using the DCF thus proving the validity of the script.

Keywords — BER, DCF, MATLAB, Q-Factor, SMF.

I. INTRODUCTION

The last decade has seen a shift from the third generation (3G) network to the fifth-generation network (5G). This has resulted to very high-speed communication, machine to machine connectivity and ultra-low latency, internet of things and so on [1]. This has led to applications that use a lot of bandwidth thereby generating much traffic. Fiber optics cables act as an excellent backhaul for this generated traffic because of its huge bandwidth. Fiber optics are long thin strands of glass with an approximate diameter of the human hair. Other advantages of fiber optics include immunity to electromagnetic interference, low loss transmission, signal security and abundant availability of its raw material.

In fiber optics communication, Information (voice, data or video) are transmitted through the glass in the form of light. The light acts as an electromagnetic carrier which is modulated to carry information [2]. Transmission through fiber optics cables is affected by several limitations especially as the distance increases. As the communication networks evolved to longer distances and higher bit rates, the linear effect of fibers, which are attenuation and dispersion, became important limiting factors [3].

In general, dispersion refers to the spreading of the pulses that make up a signal as it travels along the fiber. It is as a result of the physical property of the optic fiber. Single mode

fibers (SMF) are mostly used in high-speed optical networks are susceptible to chromatic dispersion which leads to pulse broadening [4]. This occurs because of variation in propagation velocity with wavelength. This means that some wavelengths will reach the end of the fiber before others causing a propagation delay.

A key technology for long-haul fiber links is therefore 'dispersion compensation'. The most common solution has been 'dispersion compensating fiber' (DCF), which is simply fiber in which the chromatic dispersion has been engineered to be the exact opposite of the dispersion in the fiber link. This work aims to write a program to calculate the exact length of DCF to be used, the number of amplifiers to be used and the positions the individual amplifiers are to be placed while designing a link budget for a fiber optic communication network.

II. METHODOLOGY

Tables I and II show different parameters inputted into MATLAB program. The program also takes care of the budget analysis. The formulas used for the program are given below:

$$\text{Chromatic dispersion} = DL\Delta\lambda \quad (1)$$

where D = Dispersion co-efficient;
 L = Length of fiber;
 $\Delta\lambda$ = spectral line width.

$$P_o - P_i = \text{Loss of SMF} + \text{Loss of DCF} + \text{System Margin} \quad (2)$$

where $P_o - P_i$ = transmit power – receiver power = total losses.

$$n \times \text{amplifier gain} = P_o - P_i \quad (3)$$

where n = number of amplifiers.

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TABLE I: PARAMETERS FOR SIMULATION 1

Parameter	Value
Transmit power	-3 dB
Receiver sensitivity	-25 dB
End to End Parameter	100 Gbps
End-to-End distance	300 km
Min BER	e-09
SMF Parameters	Value
Attenuation at 1560	0.20 dB/Km
Chromatic dispersion coefficient	16 ps/km.nm
Splice and connector loss	0.05 dB/km
System Margin	6
DCF Parameters	Values
Chromatic dispersion coefficient	-80 pm/km.nm
Attenuation	0.55 dB/km
Amplifier gain	20 dB

TABLE II: PARAMETERS FOR SIMULATION 2

Parameter	Value
Transmit power	-2 dB
Receiver sensitivity	-28 dB
End to End Parameter	100 Gbps
End-to-End distance	420 km
Min BER	e-09
SMF Parameters	Value
Attenuation at 1560	0.27 dB/Km
Chromatic dispersion coefficient	16.34 ps/km.nm
Splice and connector loss	0.07 dB/km
System Margin	7
DCF Parameters	Values
Chromatic dispersion coefficient	-80 pm/km.nm
Attenuation	0.55 dB/km
Amplifier gain	20 dB

III. OPTISYSTEM SIMULATION

To validate the results from the MATLAB scripts, the values gotten are used to run a simulation on Opti system. The system is divided into three sections; transmitter, channel and receiver section. The transmitter section is made up of a Pseudo-random bit sequence generator, NRZ generator, Continuous Wave (CW) laser, Mach-Zehnder modulator. The channel consists of the SMF, DCF and Amplifiers. The Receiver section is made up of the Bessel optical filter, optical receiver and BER analyzer.

The pseudo random bit sequence generator outputs a binary sequence of pseudo random bits (pulses of 0s and 1s). The generated bits are fed into the NRZ Pulse generator. The NRZ pulse generator produces a series of non-return to zero pulses that are coded by a digital signal input into an electrical signal. The CW Laser generates a steady light beam with a very stable output power. The light generated by the CW laser together with the output from the NRZ Pulse generator is fed into the Mach-Zehnder Modulator (MZM). The MZM converts the electrical input to optical signals.

The capacity of the optical link (100 Gbps) is divided into sections of 10 Gbps and multiplexed using a WDM Mux into a fiber optic cable. At the receiving side, the optical signal is demultiplexed using the WDM Demux and fed into a Bessel optical Filter which helps to prevent transmission of specific wavelengths and passed to the optical receiver.

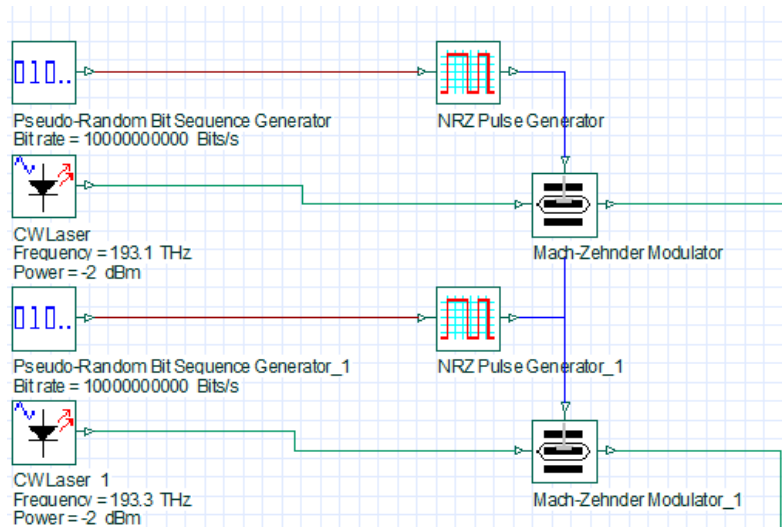


Fig. 1. Transmitter section.

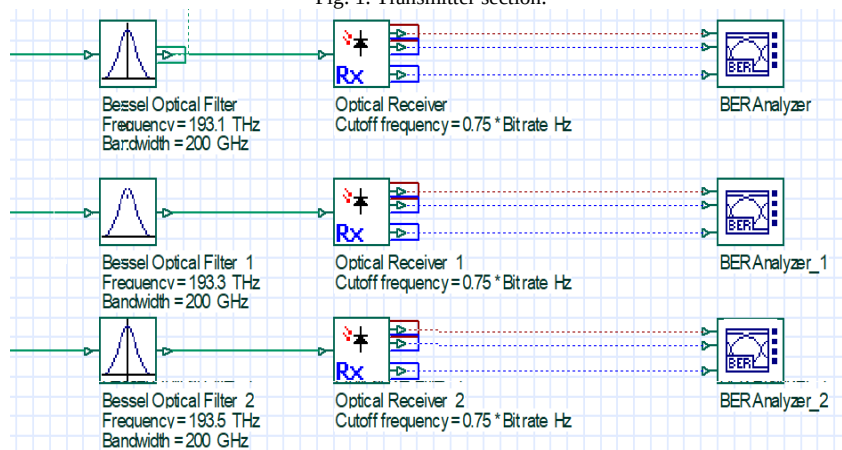


Fig. 2. Receiver Section.

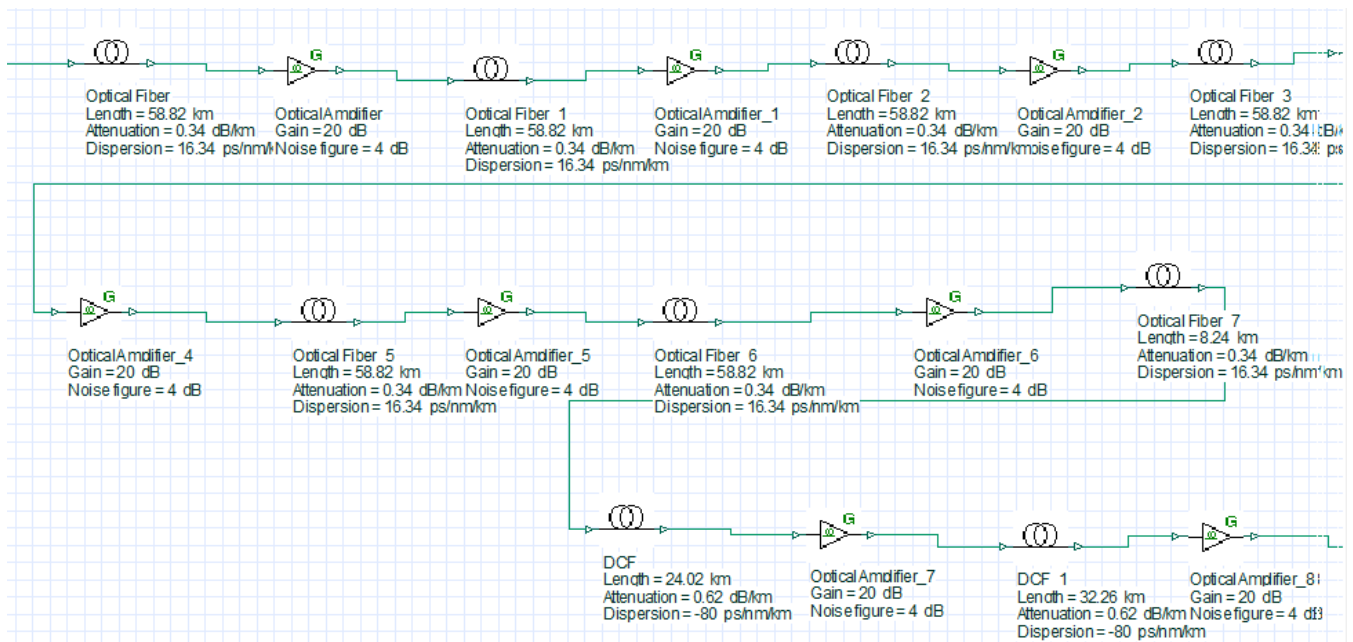


Fig. 3. Channel Section.

IV. RESULTS

The results from the MATLAB scripts are first obtained. Inputting the parameters from Table I into the MATLAB script gives the following results below:

```
The length of the DCF is 60.000 kilometers
The number of Amplifiers needed is 5.00
The amplifiers will be placed on the SMF after
every 80.00 km
The amplifiers will be placed on the DCF after
every 33.33 km
transmitter
Fiber Length of 80.00 km
Amplifier
Fiber Length of 80.00 km
Amplifier
Fiber Length of 80.00 km
Amplifier
Fiber length of 60.00 km
The SMF ends here
The next fiber Length (DCF) is spliced with last
piece of SMF
Amplifier
Fiber Length of 33.33 km
Amplifier
Fiber Length of 26.67 km
Receiver
```

Inputting the parameters from Table II into the MATLAB script gives the following results below:

```
The length of the DCF is 85.785 kilometers
The number of Amplifiers needed is 9.00
The amplifiers will be placed on the SMF after
every 58.82 km
The amplifiers will be placed on the DCF after
every 32.26 km
transmitter
Fiber Length of 58.82 km
Amplifier
Fiber Length of 58.82 km
Amplifier
Fiber Length of 58.82 km
Amplifier
Fiber Length of 58.82 km
Receiver
```

```
Amplifier
Fiber Length of 58.82 km
Amplifier
Fiber Length of 58.82 km
Amplifier
Fiber Length of 58.82 km
Amplifier
Fiber length of 8.24 km
The SMF ends here
The next fiber Length (DCF) is spliced with last
piece of SMF
Fiber Length of 24.02 km
Amplifier
Fiber Length of 32.26 km
Amplifier
Fiber Length of 29.50 km
receiver
```

The results from the MATLAB scripts are then validated using Opti system software. The results obtained from the simulation show a very low level of BER. It also gives a good Q-Factor. The Q-Factor indicates how distorted a pulse is [5]. The higher the BER, the lower the Q-Factor (i.e., the higher the level of distortion). The eye diagrams showing the Q Factor and BER for the design links are given below. Table 3 shows the various BER and Q Factor values obtained from the design links. The average BER values obtained were 7.6857e-17 and 5.8036e-10 which satisfied our minimum BER

TABLE III: VARIOUS BER AND Q FACTORS USING PARAMETERS FROM TABLES I AND II

BER from Table 1	BER from Table 2	Q-Factor from Table 1	Q-Factor from Table 2
6.56501e-042	1.59625e-020	13.5004	9.19476
2.29205e-027	4.01529e-017	10.7622	8.32022
1.0447e-023	9.71794e-014	9.96325	7.34154
4.85078e-024	8.72531e-015	10.042	7.6635
8.78023e-024	1.01108e-014	9.98267	7.64531
6.76613e-030	9.77194e-014	11.2957	7.3345
1.85709e-021	4.74881e-009	9.4343	5.72337
5.54087e-020	1.20788e-012	9.07095	6.99926
1.38549e-017	9.08452e-013	8.4463	7.04472
7.5466e-016	1.05245e-009	7.96426	5.59815
Average	Average	Average	Average
7.6857e-17	5.8036e-10	10.046203	7.286533

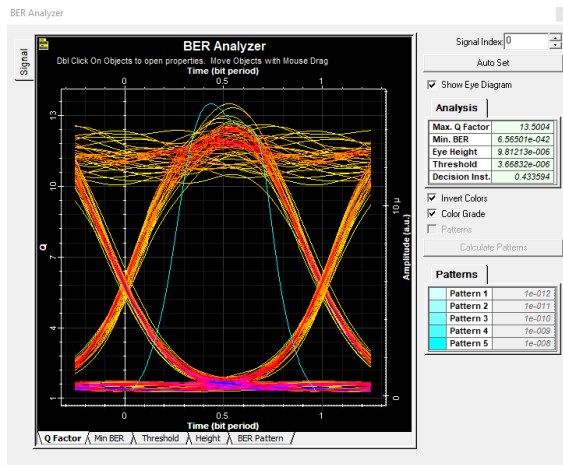


Fig. 4a. BER of 300 km Link (6.565e-042).

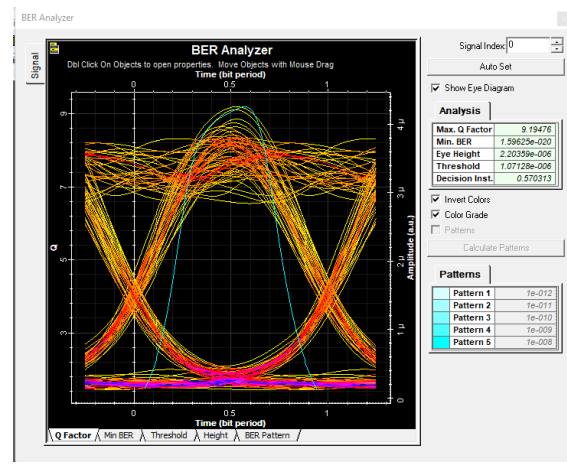


Fig. 4b. BER of 420km Link (1.59e-20).

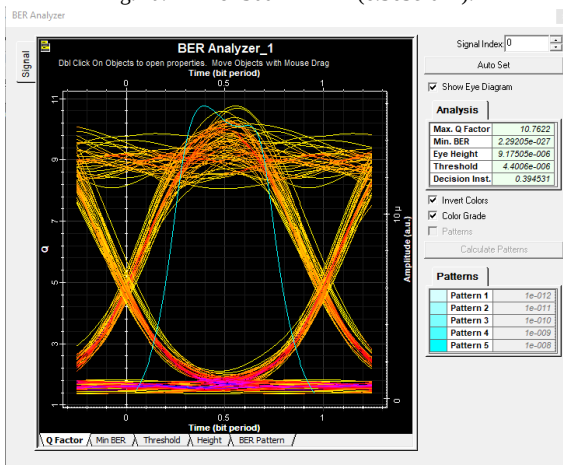


Fig. 5a. BER 1 of 300 km Link (2.292e-027).

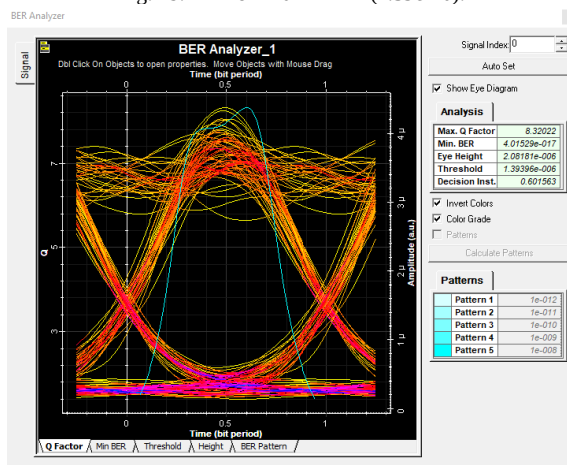


Fig. 5b. BER 1 of 420km Link (4.015e-17).

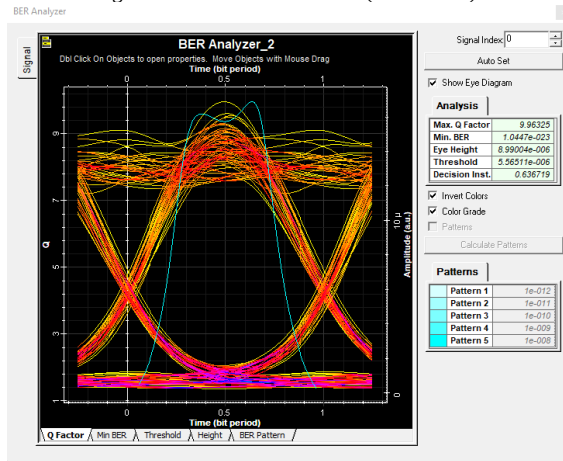


Fig. 6a. BER 2 of 300 km Link (1.0447e-023).

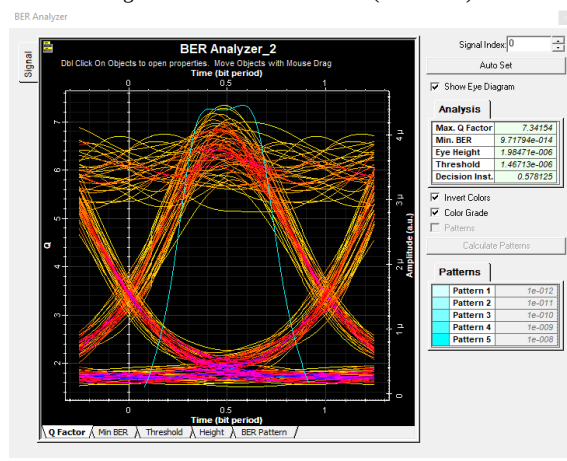


Fig. 6b. BER 1 of 420km Link (9.71e-014).

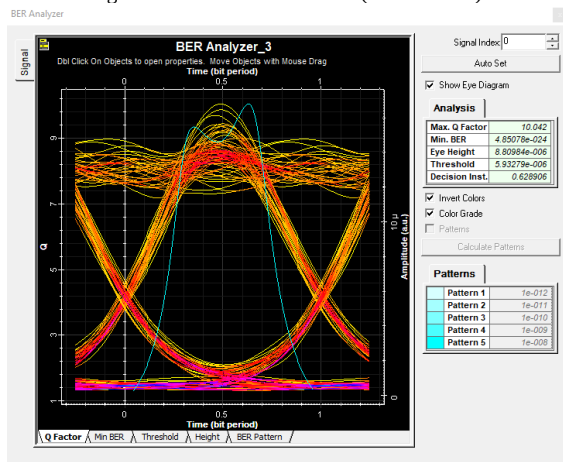


Fig. 7a. BER 3 of 300 km Link (4.85e-024).

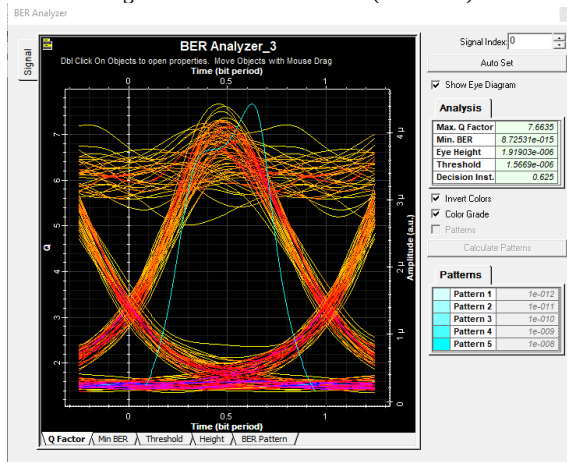


Fig. 7b. BER 3 of 420km Link (8.73e-015).

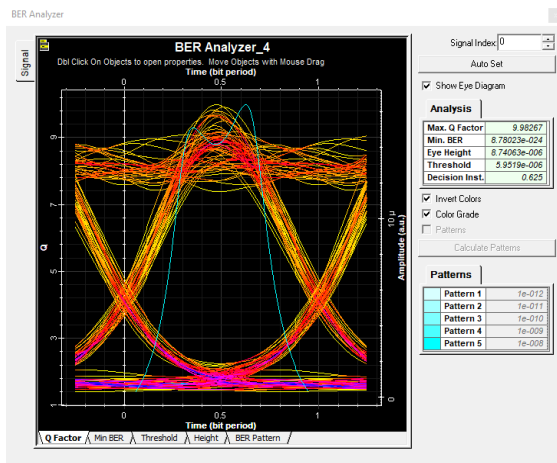


Fig. 8a. BER 4 of 300 km Link (1.31e-021).

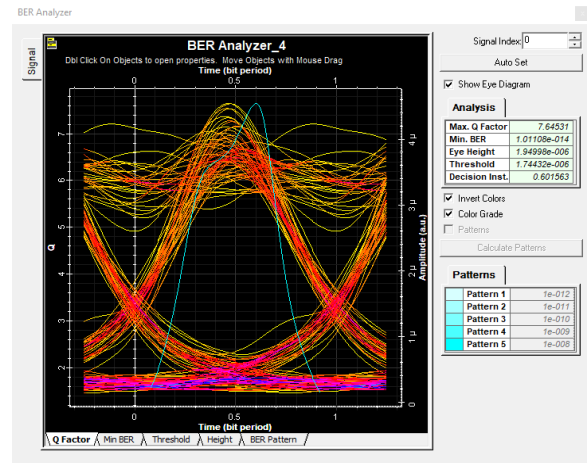


Fig. 8b. BER 4 of 420km Link (1.01e-014).

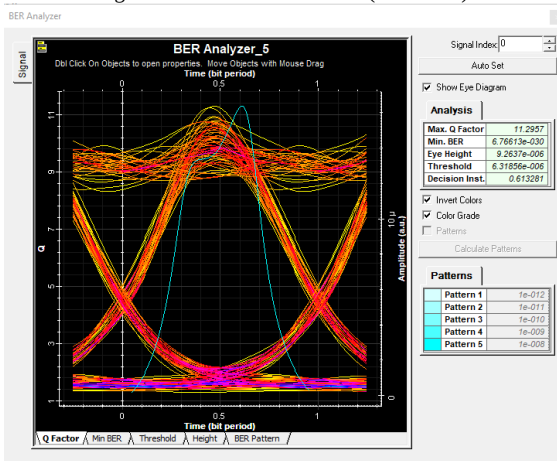


Fig. 9a. BER 5 of 300 km Link (6.766e-030).

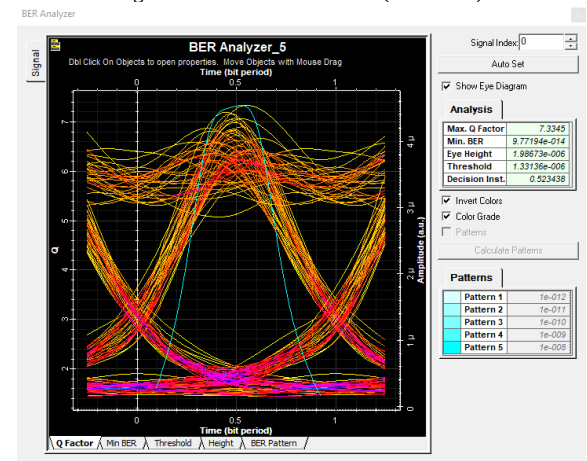


Fig. 9b. BER 5 of 420km Link (9.77e-014).

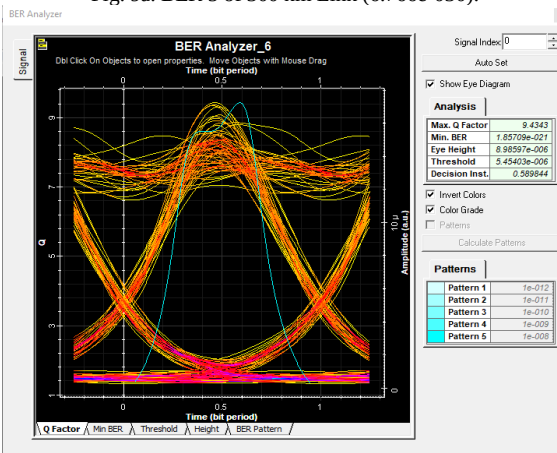


Fig. 10a. BER 6 of 300 km Link (1.857e-021).

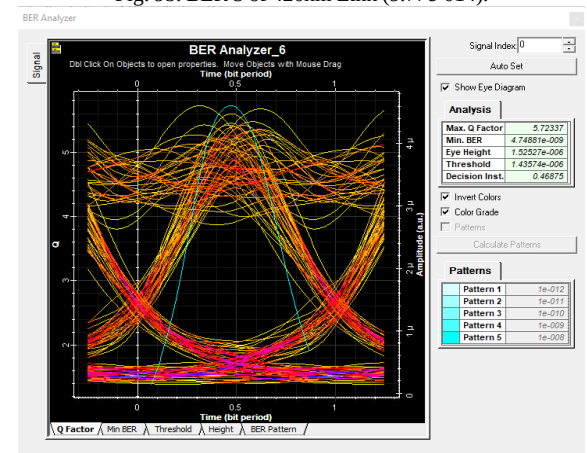


Fig. 10b. BER 6 of 420km Link (4.75e-009).

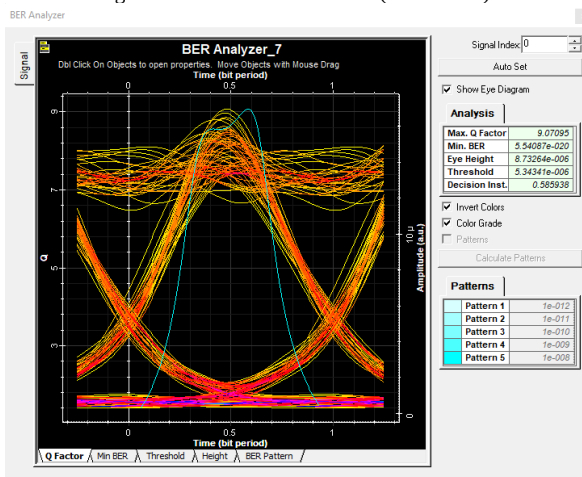


Fig. 11a. BER 7 of 300 km Link (5.54e-020).

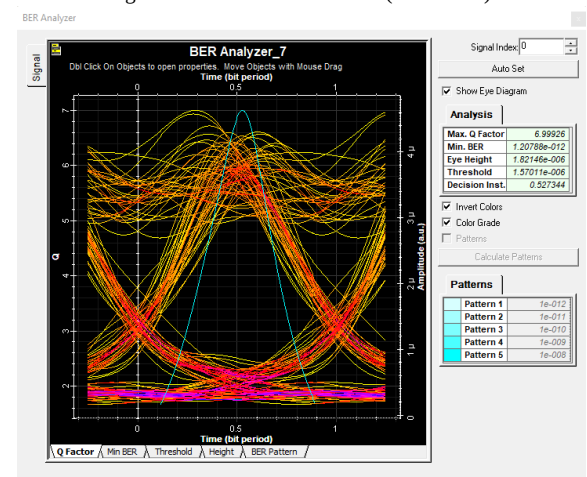


Fig. 11b. BER 7 of 420km Link (1.21e-012).

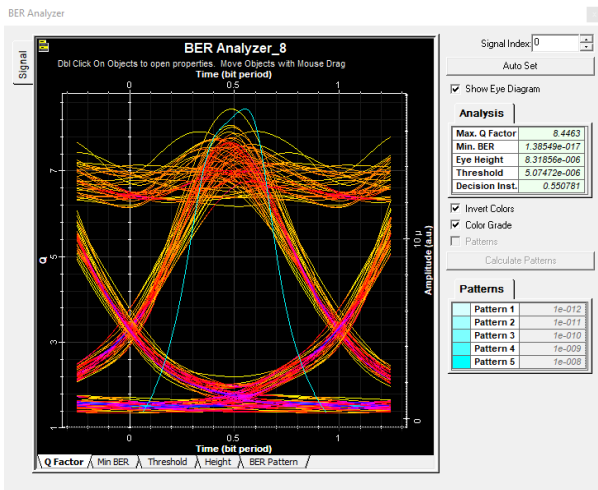


Fig. 12a. BER 8 of 300 km Link (1.385e-017).

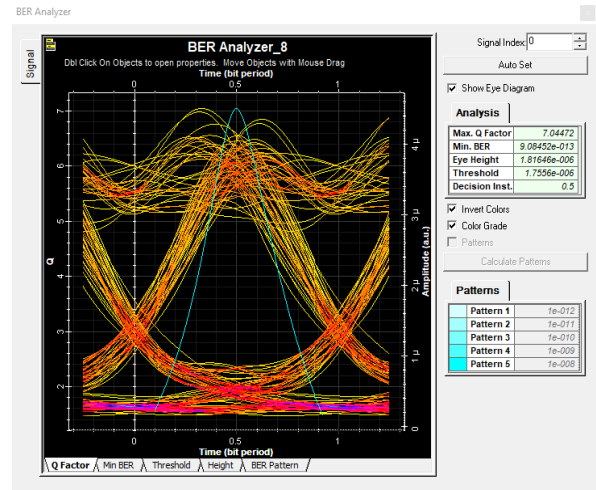


Fig. 12b. BER 8 of 420km Link (9.08e-013).

V. CONCLUSION

The aim of this paper is to write a dynamic code using MATLAB that helps compensates for the effect of dispersion in single mode fiber with the aid of dispersion compensating fiber. The code helps to calculate the length of DCF needed, the number of amplifiers and the positions where the amplifiers are to be placed. The MATLAB results were also verified using Opti system software. The minimum requirement of e-09 was met. The best BER met was 6.00128e-022 which had a Q-Factor of 9.55592. The average BER values gotten with simulation parameters of tables 1 and 2 were 7.6857e-17 and 5.8036e-10 respectively. The average Q-Factor values of 10.046203 and 7.286533 were also gotten respectively, thus proving that we designed efficient transmission links using the parameters from Tables I and II.

APPENDIX MATLAB Code

The MATLAB script for the simulation is given as follows.

```
fiberLength = input('enter length of single
mode optical cable in km \n');
TransPower = input('enter transmit power in
dB \n');
ReceivePower = input('enter receive power in
dB \n');
spectralWidth = input('enter spectral width
in nm \n');
SMFatt = input('enter attenuation of SMF in
dB/Km \n');
SMFDMat = input('enter chromatic dispersion
coefficient of SMF \n');
SpliceConnectorLoss = input('enter splice and
connector loss in dB/Km \n');
Margin = input('enter system Margin \n');
DCFatt = input('enter attenuation of DCF in
dB/Km \n');
DCFDMat = input('enter chromatic dispersion
coefficient of DCF \n');
Gain = input('enter Amplifier gain in dB
\n');

% Finding Length of DCF
```

```
SMFDispersion = SMFDMat * spectralWidth *
fiberLength;
DCFLength = (SMFDispersion
/(DCFDMat*spectralWidth))* -1;
fprintf('The length of the DCF is %4.3f
kilometers \n',DCFLength);

% To find number of amplifiers
SMFLoss = (SMFatt + SpliceConnectorLoss)*
fiberLength;
DCFLoss = (DCFatt + SpliceConnectorLoss)*
DCFLength;
TotalLoss = SMFLoss + DCFLoss + Margin;
Power = TransPower - ReceivePower;
AmpN = (TotalLoss - Power)/Gain;
AmpNo = ceil(AmpN);
fprintf('The number of Amplifiers needed is
%4.2f \n', AmpNo);

% To get the position of the amplifiers
SMFPosition = Gain/(SMFatt +
SpliceConnectorLoss);
DCFPosition = Gain/(DCFatt +
SpliceConnectorLoss);
fprintf('The amplifiers will be placed on the
SMF after every %4.2f km \n',SMFPosition);
fprintf('The amplifiers will be placed on
the DCF after every %4.2f km
\n',DCFPosition);

% To show how the fiber and amplifiers are
placed
disp('transmitter')
while fiberLength>SMFPosition
    fiberLength = fiberLength-SMFPosition;
    fprintf('Fiber Length of %4.2f km
\n',SMFPosition)
    disp('Amplifier')
end
if fiberLength ~= 0
    fprintf(' Fiber length of %4.2f km \n',
fiberLength)
    disp('The SMF ends here')
    disp('The next fiber Length (DCF) is
spliced with last piece of SMF')
end
if DCFPosition > fiberLength
    dcfLength = DCFPosition - fiberLength;
    fprintf('Fiber Length of %4.2f km
\n',dcfLength)
    disp('Amplifier')
```

```
DCFLength = DCFLength - dcfLength;

while DCFLength>DCFPosition
DCFLength = DCFLength-DCFPosition;
fprintf('Fiber Length of %4.2f km
\n',DCFPosition)
disp('Amplifier')
end

else if DCFPosition < fiberLength
disp('Amplifier')
while DCFLength>DCFPosition
DCFLength = DCFLength-DCFPosition;
fprintf('Fiber Length of %4.2f km
\n',DCFPosition)
disp('Amplifier')
end
end

end

if DCFLength ~= 0
fprintf('Fiber Length of %4.2f km \n',
DCFLength)
end

disp('receiver')
```

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