The effect of the optical fiber design on reducing the nonlinear characteristics of the optical fiber

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Abstract. Fiber Bragg Grating FBG Works as a filter within a specific range to counteract the light whose wavelength is within the filter range and allows the light whose wavelength is outside the range of the filter to pass through the carrier light-medium. In communications (fiber-optic) the FBG is used to separate the optical signals. In this paper, the nonlinear optical properties study for optical transmission that consists of an optical transmitter that is transmitting the signal to two different fiber design first is single-mode fiber and second is Coarse Wavelength division multiplexing (CWDM) fiber. Then we enter the Bragg Grating on these two fiber and studies the effect of the Bragg on them. The nonlinear optical characteristic (Q factor and bit error rate BER) is calculated for different fiber length (Km) and input power (dBm) applied on these two fibers and found the best fiber type that has a high Q factor and zero BER. By using optiwave software and matlab (R2015) software program to measure the quality factor, eye diagram and BER of the received signal at the receiver, Results are obtained and installed with graphs and tables.

1. Introduction

In optical fiber communication information is transmitted from transmitter to receiver by using light as a carrier and optical fiber as a channel [1]. The transmitted signal suffers from many problems and the worse one is dispersion which is responsible for degradation in system performance. It is possible to reduce dispersion using different methods of optical communication systems [2]. The processing can be by fiber grating, different optical amplifiers, different adjustment techniques, and fiber compensate for dispersion [3]. In optical fiber communication, many different wavelengths that carry independent signal channels along one fiber can be transmitted simultaneously the technique of combining many wavelengths onto the same fiber is known as Wave Length Division Multiplexing (WDM)[2]. In WDM the various wavelength channels must be spaced properly to overcome interchannel interference. Channels in optical fiber communication classified into two types’ single-channel system and multichannel system which in turn classified into three types WDM, CWDM, and DWDM [3]. The objective of this paper is to use two different optical fiber design, to calculate the Q factor and BER for the optical signal that received to the receiver for different fiber lengths.
2. Fiber Bragg Grating

The basic principle behind FBG is the Fresnel reflection as shown in figure (1), where the light moving between the different refractive media may be reflected on the facade and broken[3]. The refractive index usually rotates along a specific length. The reflected wavelength ($\lambda_B$), “called the Bragg wavelength” is defined by the relationship [4],

$$\lambda_B = 2n_{eff}\Lambda$$  \hspace{1cm} (1)

Where $\Lambda$: “The grating period”, $n_{eff}$: “is the effective refractive index of the grating in the fiber core”, which determines the speed of light propagation. ($\Delta \lambda$), is given by[4],

$$\Delta \lambda = \left[\frac{2\delta n_0\eta}{\pi}\right] \lambda_B$$  \hspace{1cm} (2)

Where $\delta n_0$ : “is the variation in the refractive index” ($n_3 - n_2$), and $\eta$ : “is the fraction of power in the core” [4]. The peak reflection ($P_B(\lambda_B)$) is approximately given by,

$$P_B(\lambda_B) \approx tanh^2\left[\frac{N\eta(\omega)\delta n_0}{n}\right]$$  \hspace{1cm} (3)

Where $N$ : “is the number of periodic variations”[3,4].

![Figure 1. Fiber Bragg Grating](image)
3. Quality factor and BER analysis

The bit error rate (BER) is the final measure of transmission quality. Due to the influence of factors such as noise, nonlinear effects and dispersion (PMD/CD), waveforms of fiber optic signals will be distorted. Therefore, bit errors exist when the receiver converts the light signals to electrical signals [5].

\[
Q = \frac{I_1 - I_0}{\sigma_1 - \sigma_0}
\]  

\(I_1\) and \(I_0\) are the mean value and variance output by Gaussian pulse 1, \(\sigma_1\) and \(\sigma_0\) are the mean value and variance output by Gaussian pulse [5].

\[
BER = \frac{1}{2} \text{erfc}\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{1}{\sqrt{2\pi}Q} \exp\left(-\frac{Q^2}{2}\right)
\]

Q and BER have one-to-one comparison. The Q value of the unit can represent unit dB, to represent optical power [4, 5].

4. Eye diagram

The eye diagram data is a methodology for the representation and analysis of a high-speed digital signal. The outline of the eye allows for the identification and quick identification of the main parameters of the electrical quality of the signal [1,3]. The data eye diagram of a digital waveform is created by folding the corresponding waveform fragments from each bit into a signal graph with the amplitude of the signal on the vertical axis and the time on the horizontal axis. By repeating this structure in many wave samples, the resulting graph will represent average signal statistics and will resemble the eye. The eye slot corresponds to a single bit period and is usually called the interval display of the module (UI) in the eye chart [3]. The open-eye view determines the interval at which the receiving signal samples can be sampled without error due to interference from adjacent pulses (known as intersymbol interference) as shown in figure (2). The higher the eye closure, the greater the difficulty of distinguishing between 1s and 0s in the signal [3].

\[
\text{Noise Margin (percent)} = \frac{V_1}{V_2} \times 100\%
\]

Figure 2. The General configuration of an eye diagram. Figure 3. Simplified eye diagram.
Figure (3) shows the simplified eye diagram. The rate of eye closure changes at the time of sampling. Timing jitter (also referred to as eye clutter or phase deformation) in the fiber-optic system results from future interference and pulse distortion in optical fibers [5].

\[
\text{Time jitter (percent)} = \frac{\Delta T}{T_b} \times 100\% \quad (7)
\]

5. CWDM
Coarse Wavelength division multiplexing (CWDM), is a means of combining multiple signals on lasers with different wavelengths for transmission over fiber optic cables, so that the number of channels is less than the number of Dense Wavelength Division Multiplexing (DWDM) but at wavelength more than Wavelength Division Multiplexing (WDM)[6]. WDM transports some channels and takes advantage of the widest distance between channels for distances of up to 60 km. The wider CWDM distance up to 20 nm, compared with 1.6 nm DWDM, can withstand high-temperature fluctuations [7].

6. Computer modeling
Optiwave system is a modern optical communication system [7]. We can simulate the optical communication system using OPTI system software as described in figure (4). In this step of the project, we adjusted the input power value until we reached the optimal values were found for BER \((10^{-9})\), the modified Q=6 factor. The first channel used is a single-mode fiber with Bragg grating and the second channel used is CWDM fiber with Bragg grating, simulated parameters are shown in the table (1).
**Figure 4.** The computer model.

**Table 1.** Simulation parameters.

| Parameter                      | Value     |
|-------------------------------|-----------|
| Central frequency (THz)       | 193.1     |
| Power (dBm)                   | 0-15      |
| Wave length (nm)              | 1550      |
| Fiber length (Km)             | 10-50     |
| Attenuation (dB/Km)           | 0.2       |
| Dispersion (ps/nm.km)         | 16.75     |
| Dispersion slop (ps/nm²/km)   | 0.75      |
| Bragg grating length (mm)     | 0-10      |
Figure 5. Model design of the simulated system using Optisystem software.

7. Simulated results and discussion

In figure (6) the optical spectrum analyzer used to show the relation between wavelength and power that output from (a) optical transmitter. (b) The output from the optical fiber with FBG.

Figure 6. The relation between wavelength and power that output from (a) the optical transmitter, (b) the single-mode fiber with FBG.

In figure (7) the optical spectrum analyzer shows the relation between wavelength and power that outside from optical transmitter, the CWDM fiber with FBG.

Figure 7. The relation between wavelength and power that output from (a) the optical transmitter, (b) CWDM fiber with FBG.

Figure 8. The relation between Quality factor and BER for single-mode fiber with FBG.
In figure (8) and (9) explain the relationship between the BER and Q factor in fiber optic and CWDM fiber, and notes that the BER decreasing with Q factor increasing, and the CWDM fiber with FBG is better results than single-mode fiber. When we used the above fibers but without FBG shown in figure (10, 11) the result BER is greater, and Q factor less than used the fiber with FBG.

The eye diagram analyser used as an oscilloscope to show the eye chart that gives a frequency sampling of digital data from the receiver, figures (12-15) shows the eye diagrams of the received signal from the single-mode fiber and CWDM fiber with FBG for different input powers (0, 15) dBm and different fiber lengths (10, 60) Km. from this figures notes that the Q factor and BER inversely proportional with fiber length and input power, the single-step fiber with Bragg Grating is better fiber...
design than CWDM with Bragg Grating because that have Q factor higher and less BER than CWDM.

![Figure 12. The eye diagram for single-mode fiber with FBG at L=10km and Q=67.567.](image12)

![Figure 13. The eye diagram for single-mode fiber with FBG at L=60Km and Q=14.4938.](image13)

![Figure 14. The eye diagram for CWDM fiber with FBG at L=10km and Q=65.046.](image14)

![Figure 15. The eye diagram for CWDM fiber with FBG at L=60Km and Q=14.4577.](image15)

The tables (2-5) explain the effect using the Bragg Grating on the single-step fiber and CWDM fiber with different fiber length and input power. This calculation has been drawn as a figure (17-20).

**Table 2.** The Quality factor and BER for single-mode fiber with FBG.

| Power(dBm) | Fiber length(Km) | Quality factor | Bit Error Rate |
|------------|------------------|----------------|----------------|
| 0          | 10               | 67.567         | 0              |
| 6          | 30               | 29.6398        | 1.7688e-193    |
| 10         | 50               | 20.8837        | 3.66168e-097   |
| 15         | 60               | 14.4938        | 4.58099e-048   |
Table 3. The Quality factor and BER for single-mode fiber without FBG.

| Power(dBm) | Fiber length(Km) | Quality factor | Bit Error Rate |
|------------|------------------|----------------|----------------|
| 0          | 10               | 45.4968        | 0              |
| 6          | 30               | 18.3132        | 2.28846e-075   |
| 10         | 50               | 16.6296        | 1.97738e-062   |
| 15         | 60               | 12.0892        | 4.12508e-034   |

Table 4. The Quality factor and BER for CWDM with FBG.

| Power(dBm) | Fiber length(Km) | Quality factor | Bit Error Rate |
|------------|------------------|----------------|----------------|
| 0          | 10               | 65.046         | 0              |
| 6          | 30               | 29.01          | 1.86635e-185   |
| 10         | 50               | 20.6611        | 3.761818e-095  |
| 15         | 60               | 14.4577        | 7.70499e-048   |

Table 5. The Quality factor and BER for CWDM without FBG.

| Power(dBm) | Fiber length(Km) | Quality factor | Bit Error Rate |
|------------|------------------|----------------|----------------|
| 0          | 10               | 47.8127        | 0              |
| 6          | 30               | 18.1134        | 8.73491e-074   |
| 10         | 50               | 16.6407        | 1.65205e-062   |
| 15         | 60               | 12.0829        | 4.4781e-034    |

The single-step fiber has been selected because of its best results in the existence of Bragg Grating. Therefore, we change the Grating period ($\Lambda$) in (mm), then calculate the Q factor and BER, the results shown in tables (6-9). And this calculation plotted in figure (16).

Table 6. The quality factor and BER for single-step fiber at fiber length=10 Km and input power=0 dBm.
| Grating Period (mm) | Quality factor | BER       |
|---------------------|---------------|-----------|
| 1                   | 8.90149       | 2.75489e-019 |
| 2                   | 28.8003       | 1.04986e-182 |
| 3                   | 47.4462       | 0         |
| 4                   | 60.6238       | 0         |
| 5                   | 67.567        | 0         |
| 6                   | 67.7306       | 0         |
| 7                   | 64.1257       | 0         |
| 8                   | 60.024        | 0         |
| 9                   | 57.6504       | 0         |
| 10                  | 58.6543       | 0         |

Table 7. The quality factor and BER for single-step fiber at fiber length=30 Km and input power=6 dBm.

| Grating Period (mm) | Quality factor | BER       |
|---------------------|---------------|-----------|
| 1                   | 12.4577       | 6.16122e-036 |
| 2                   | 19.5331       | 2.36057e-085 |
| 3                   | 22.9032       | 1.59808e-116 |
| 4                   | 26.1783       | 1.74909e-151 |
| 5                   | 29.6393       | 1.7688e-193  |
| 6                   | 33.846        | 1.66269e-251 |
| 7                   | 38.4502       | 4.94066e-324 |
| 8                   | 40.7117       | 0          |
| 9                   | 41.3952       | 0          |
| 10                  | 39.4935       | 0          |

Table 8. The quality factor and BER for single-step fiber at fiber length=50 Km and input power=10 dBm.
Table 9. The quality factor and BER for single-step fiber at fiber length=60 Km and input power=15 dBm.

| Grating Period (mm) | Quality factor | BER         |
|---------------------|----------------|-------------|
| 1                   | 11.4254        | 1.23775e-030 |
| 2                   | 12.78          | 7.41997e-037 |
| 3                   | 13.4852        | 6.6189e-042  |
| 4                   | 14.101         | 1.29308e-045 |
| 5                   | 14.4938        | 4.58099e-048 |
| 6                   | 14.6373        | 5.54186e-049 |
| 7                   | 14.6457        | 4.90114e-049 |
| 8                   | 14.8314        | 3.16475e-050 |
| 9                   | 15.2879        | 3.3111e-053  |
| 10                  | 15.7524        | 2.47314e-056 |

(a) Quality factor with fiber Bragg Grating FBG for different input power

(b) BER with fiber Bragg Grating length for different input power
Figure 16. In single step fiber with FBG (a) the quality factor grating period for different input power (b) BER with Grating period for different input power.

(a) 
(b) 

Figure 17. (a) the quality factor with fiber length with and without FBG in a single-mode fiber channel. (b) the quality factor with I/P power with and without FBG in a single-mode fiber channel.

(a) 
(b) 

Quality factor with fiber length with and without FBG used single-mode fiber channel

Quality factor with input power with and without FBG used single-mode fiber channel

Quality factor with fiber length with and without FBG used CWDM fiber channel

Quality factor with power with and without FBG used CWDM fiber channel
Figure 18. (a) The quality factor with fiber length with and without FBG in single-mode CWDM fiber channel. (b) The quality factor with I/p power with and without FBG in the CWDM fiber channel.

![Graphs showing quality factor versus fiber length and power](image)

Figure 19. (a) BER with fiber length with and without FBG in a single-mode fiber channel. (b) BER with i/p power with and without FBG in a single-mode fiber channel.

![Graphs showing BER versus fiber length and power](image)
Figure 20. (a) BER with fiber length with and without FBG in the CWDM fiber channel. (b) BER with i/p power with and without FBG in the CWDM fiber channel.

8. Conclusion
In this paper, after using two different fiber designs in many situations we conclude that when used the fibers without FBG the CWDM has a higher Q factor and lower BER than single-step fiber and this is clearly in the tables and figures. When we enter FBG in the two fibers found that the single-step fiber has a higher Q factor and lower BER than CWDM fiber. After choosing the better fiber with FBG, study the effect of the Grating period on the single-step fiber with different fiber length and input power, we conclude that the Q factor and BER for each state differ dependent on the Grating period. So the higher Q factor in length fiber $L=10$ Km is at Grating fiber $\Lambda=5$mm, while in $L=30$ Km and $L=50$ Km, $\Lambda=9$ mm, while in $L=60$ Km, $\Lambda=10$ mm. So the Grating period of the FBG inversely proportional to fiber length and input power. Therefore the good fiber design used to transmit the optical signal to a receiver with high-quality factor (Q) and zero BER is the single step fiber with Bragg Grating.

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