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DISPERSION COMPENSATION OF DCF in Optical Communications

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Abstract* : *This article deals with the causes and characteristics of chromatic dispersion in optical fibers and also its effects on signal transmission. We aim to understand the problem in a more mathematical approach and discuss the ways of dispersion compensation through simulations in Optisystem software. In this article we focus on the two important methods to compensate the chromatic dispersion- Dispersion compensation using fiber Bragg grating (FBR)Dispersion compensation using dispersion compensation fiber (DCF)After the simulations the methods are analysed and concluded by choosing which a better system to compensate chromatic dispersion is.

Key words: Chromatic dispersion, Fiber Bragg Grating(FBG), Dispersion Compensation Fiber(DCF)**,**

I. INTRODUCTION

Chromatic dispersion is a phenomenon that is an important factor in fiber optic communications. It is the result of the different colors, or wavelengths, in a light beam arriving at their destination at slightly different times. The result is a spreading, or dispersion, of the on-off light pulses that convey digital information. The receiver cannot correctly predict whether a transmitter in a specific bit interval sent a value of logical one or zero. The distortion of the transmitted information will then increase the bit error rate. Special care must be taken to compensate for this dispersion so that the optical fiber delivers at its maximum capacity. There are two types of chromatic dispersion:

- Material dispersion
- Wave guide dispersion

The *material* dispersion is caused by the dependence of the refractive index of the material used for fiber manufacturing on the light wavelength.

V=C/n
C is speed of light in vacuum,
n is refractive index

The *waveguide* dispersion is caused by boundary condition at the fiber surface which is influenced by geometrical parameters of the fiber. The geometrical parameters are mainly: the transversal profile of the refractive index and of the fiber core radius to the signal wavelength ratio. Consequently, the waveguide dispersion affects the speed of light passing through the fiber.

II. COMPENSATION METHODS

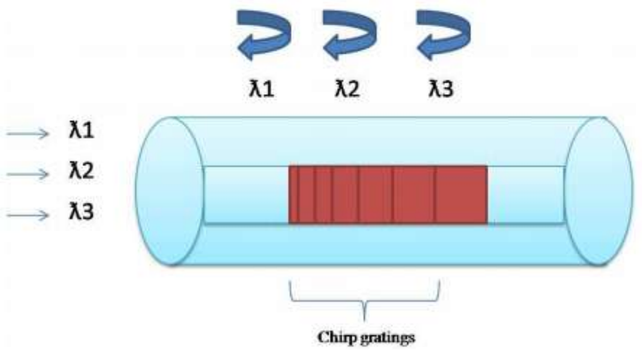
Various methods allow for compensation of the chromatic dispersion.

2.1 Dispersion compensation using fiber Bragg grating (FBG)

FBG is one of the methods to compensate chromatic dispersion. In this, propagated light which satisfies the Bragg condition is resonated by grating structure and reflected and thus we get only a small part of the signal and rest all goes out of the fiber. Hill, in 1978 demonstrated the first in-fiber Bragg grating. Fiber Bragg gratings are created by fabricating or scribing the periodic variation of refractive index into the core of a special type of optical fiber using intense ultraviolet(UV) source such as UV laser. FBG has a very narrow operating window. It is a reflective device composed of an optical fiber that contains a modulation of its core refractive index over a certain length. The Grating reflects light propagation through the fiber when its wavelength corresponds to the modulation periodicity. The reflected wavelength (λB) is called the Bragg wavelength, and defined by the relationship [1]:

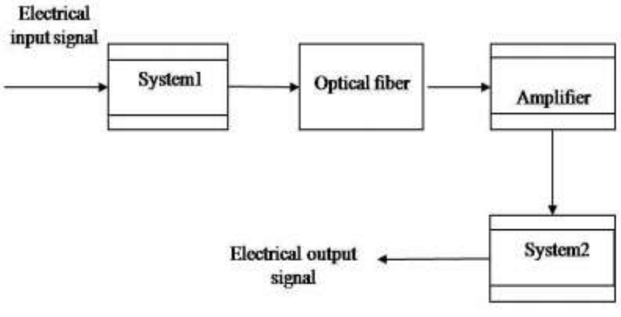
$$\lambda_b = 2n\Lambda ,$$

where n is the effective refractive index of the grating in the fiber core and Λ is the grating period. Using fiber Bragg gratings for dispersion compensation is a promising approach because they are passive optical component fiber compatible, having low insertion losses and costs. If some modifications are made to gratings of fiber Bragg gratings a better performance can be achieved. Gratings that have a non-uniform period along their length are known as Chirped FBG.

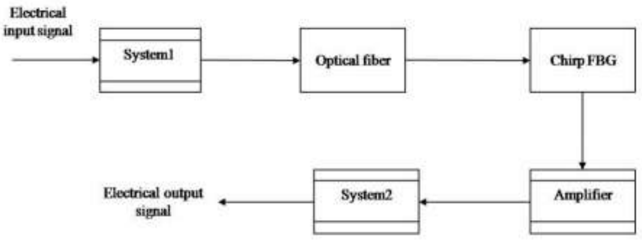


Analysis of Compensating Dispersion in Optical Communication Link Using Chirp Grating:

The proposed Block diagram to simulate transmission system without FBG and with FBG is shown in figure (a) and figure (b) respectively.



(a) A block diagram of transmission system without using FBG



(b) A block diagram of transmission system using FBG

System 1 includes a pseudo random sequence generator, non-return-zero(NRZ), a continuous wave(CW) laser with frequency 193.1 and output power 1MW and a Mach Zehnder modulator with 30dB extinction. The signal gets modulated with a non-return-zero pseudorandom sequence in mach zehnder modulator. The output of system1 is fed into optical fiber whose length is 15km and 30km, dispersion is 17ps/km/nm, dispersion slope is 0.050pm/nm2/km, and attenuation index is 0.20km. Then the dispersed wave goes into a chirp fiber bragg grating from where a better signal is achieved. The parameters used in chirp FBG are frequency, effective refractive index, length of grating, apodization function, tanh parameter, chirp function. Linear parameter and their values are 193.1THz, 1.45, 6, Tanh, 4, linear and 0.0001 respectively. The signal is then amplified in EDFA amplifier which has a gain amount of 6dB. The amplified signal pases through System 2 and we get output electrical signal. System 2 consists of a photo detector (PIN) and eye diagram analyzer.

2.2 Dispersion compensation fiber:

Conventional single mode fibers are characterized by large (~ 5-6 µm) core radii and zero dispersion occurs around 1300 nm. Operation around λ0 at 1300nm thus leads to very low pulse broadening, but the attenuation is higher than at 1550 nm. Thus, to exploit the low-loss window around 1550nm, new fiber designs were developed that had zero dispersion around 1550nm wavelength region. These fibers are called Dispersion Shifted Fibers (DSF) and have typically a triangular refractive index profiled core using DSFs operating at 1550nm, one can achieve zero dispersion as well as minimum loss in silica-based fibers.

Now, in many countries, tens of millions of kilometers of conventional single mode fibers already exist in the underground ducts operating at 1300nm. One could increase the transmission capacity by operating these fibers at 1550nm and using WDM techniques and optical amplifiers.

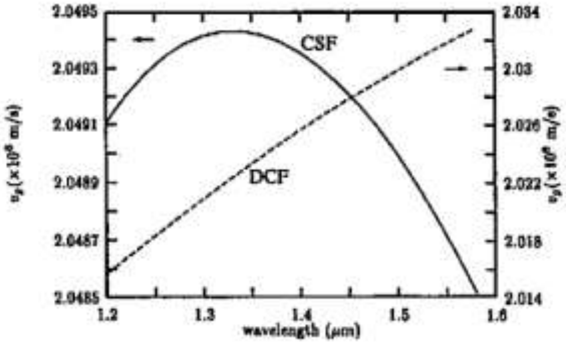
But, then there will be significant residual (positive) dispersion. On the other hand, replacing these fibers by DSFs would involve huge costs. As such, in recent years, there has been considerable work in upgrading the installed 1310nm optimized optical fiber links for operating at 1550nm. This is achieved by developing fibers with very large negative dispersion coefficients, a few hundred meters to a kilometer, which can be used to compensate for dispersion over tens of kilometers of the fiber in the link.

Compensation of dispersion at a wavelength around 1550nm in a 1310nm optimized single mode fiber can be achieved by specially designed fibers whose dispersion coefficient (D) is negative and large at 1550nm. These types of fibers are know as Dispersion Compensating Fibers (DCFs).

Consider a pulse with spectral width of $\Delta\lambda_0$ which is propagating through a fiber characterized by the propagation constant β. The spectral width $\Delta\lambda_0$ could be due to either the finite spectral width of the laser source itself or the finite duration of a Fourier transform-limited pulse. We consider the propagation of such a pulse with the group velocity given by:

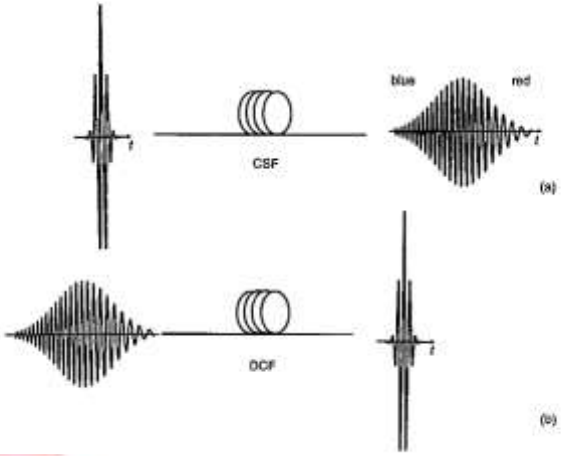
$$\frac{1}{v_g} = \frac{d\beta}{d\omega}$$

For a conventional single mode fiber with zero dispersion around 1300nm, a typical variation of v_g with wavelength is shown by the solid curve in the following figure [4].



As we can see from the above figure, v_g has a maximum value at the zero dispersion wavelength and on either side it monotonically decreases with wavelength. So, if the central wavelength of the pulse is around 1.55 μm, then the longer wavelengths will travel slower than the smaller wavelengths of the pulse. Because of this (chromatic dispersion) the pulse will get broadened. The leading edge of the output pulse is blue shifted and the trailing edge is red shifted.

Now, after propagating through such a fiber for a certain length L_1, we allow the pulse to propagate through another fiber where the group velocity varies, as shown by the dashed cure in the above figure. The longer wavelengths will now travel faster than the shorter wavelengths and the pulse will tend to reshape itself into its original form. This is the basic principle behind dispersion compensation.



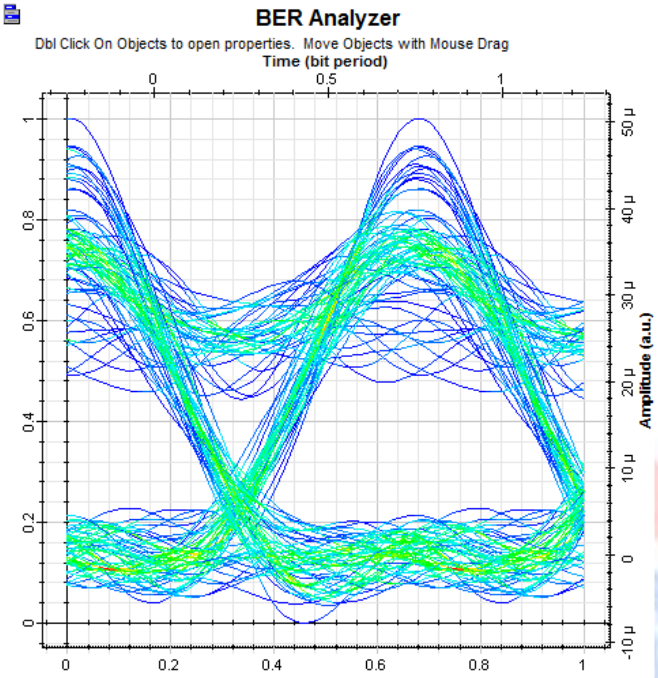
Since the DCF has to be added to an existing fiber optic limit, it would increase the total loss of the system and, hence, would pose problems in detection at the end. The length of the DCF required for compensation can be reduced by having fibers with very large negative dispersion coefficients. Thus, there has been considerable research effort to achieve DCFs with very large (negative) dispersion coefficients.

III. SIMULATION RESULTS

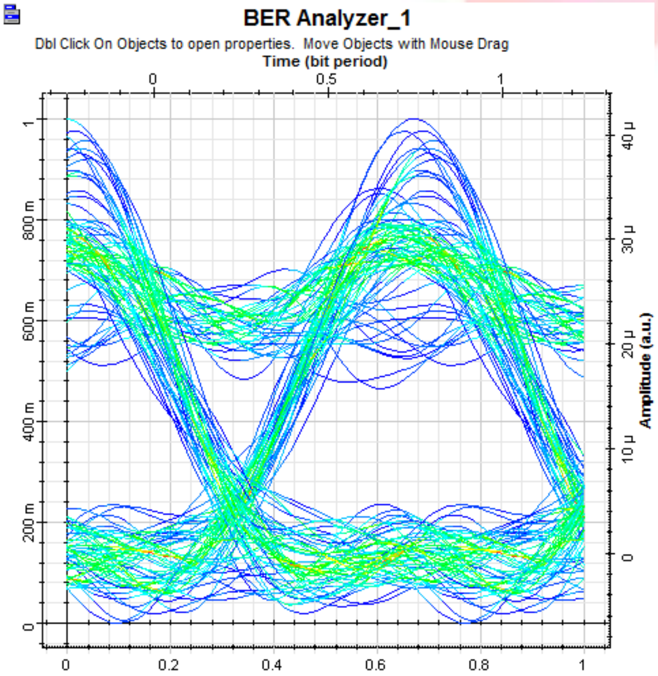
Optisystem is a software simulation tool for analysis of various optical communication systems and technologies.

3.1 Dispersion compensation using fiber Bragg grating (FBR)

In the Figure(c) there is shown a diagram of the fiber Bragg grating (FBG) compensation method. In the simulation NRZ signal with a transmission speed of 10Gbit/s was used. Signal was transmitted through a standard 120 km long single mode fiber.The results of simulation in the Optisystem program - the eye diagram without and with compensation are shown.The eye diagram is an important tool for qualitative analysis of signals used in digital communication. It provides a view on the assessment of transmission characteristics of the system and the simulator uses it to evaluate the error during the transmission of information. The inserted FBG compensation significantly reduced the influence of the chromatic dispersion.



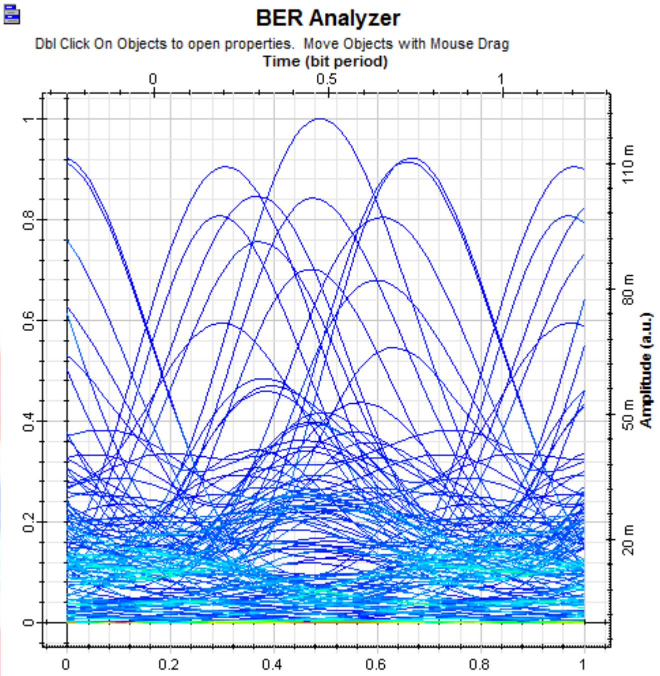
c) Eye diagram before compensation



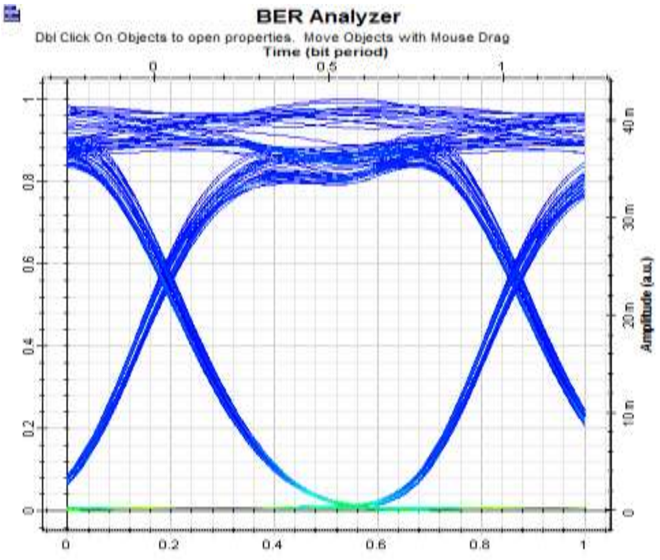
The eye diagram after FBG compensation

3.2 Dispersion compensation using dispersion compensation fiber (DCF)

Now we will compensate dispersion using an optical fiber DCF with high negative value of chromatic dispersion coefficient.



Pre dispersion compensation



Post dispersion compensation

The communication link with a total length of 120 km we prepare consists of 20 km of DCF with negative chromatic dispersion coefficient (D = -80ps.nm-1.km-1) and of a 100 km single-mode classical fiber (D = 18ps. nm-1.km-1). We distinguish between the pre-compensation and the post-compensation method of chromatic dispersion. Pre-compensation model has the DCF at the link front end and in the post-compensation model the DCF is at the link far end.

The inserted fiber reduces a chromatic dispersion again. However, the curves of the eye diagram are not as sharp as in compensation with FBG and therefore Q parameter has now the value only Q=22.

Simulation of chromatic dispersion pre-compensation even got worse results. The Q parameter reached was Q=18. BER values for the both methods are again very small and the program did not display them.

IV. CONCLUSION

The aim of this study was to describe the methods of the chromatic dispersion reduction in a classic single-mode optical fiber SMF and to illustrate it using simulation on the Optisystem software.

There were two simulations performed – dispersion compensation using the FBG and the DCF dispersion compensation. Both simulations showed significant reduction of chromatic dispersion confirming the theoretical assumptions. The comparison of eye diagrams of the two mentioned compensation methods shows that the FBG is the better method for chromatic dispersion compensation than the DCF. Further, the DCF method shows a higher attenuation, which must be compensated by optical amplifiers and so this method is less applicable than the compensation using FBG.

V. REFERENCES

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