Influence of Chromatic Dispersion in Optical Communication Systems

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Abstract--In this paper we have sutdied about chromatic dispersion and its effects on transmission of data with different bit rate in optical fibre is analyzed and various methods to reduce this effect are suggested .

Keywords-- chromatic dispersion coefficient, Mach-Zehnder interferometer ,DFB laser,DSF,DCF, Fibre Bragg Grating (FBG),Optsim, Eye diagram, Q-factor.

I. INTRODUCTION

Optical transmission systems have been managed to our demands to be able to transfer the required data volumes. Unfortunately, these requirements are increasing, forcing us to deal with problems, which we saw only in theory so far. Specifically, one of these is the chromatic dispersion influence.

Optical transmission system transmits information encoded in optical signal over long distances. The electrical signal in the transmitter at the fibre input is converted into light impulses that are transferred through the fibre to the receiver at the end of the fibre. In the receiver the light impulses are converted back to the original electrical signal. The transmission using the optical fibre has many advantages over traditional metallic (copper) transmission systems

a) optical signal propagating through fibre is attenuated less than the electric signal in the metallic line and so it can be sent over longer distances without repeaters
b) optical transmission allows much greater data capacity
c) optical signal is completely electrically isolated and it is resistant to RF interference and crosstalk.

II. CHARACTERISTICS OF OPTICAL FIBER

They are determined mainly by parameters of the optical fibre. The most important parameters are:

a) Numerical aperture (NA) – Ability of fibre to absorb light into itself (specifically the optical power). Specifically, it is the sine of the angle under which a light ray may enter the fibre to ensure the total reflection of light will occur at the fibre surface
b) Attenuation - It is the analogy of attenuation in the case of copper cables. With increasing distance from the optical source, the power of optical signal decreases.
c) Dispersion - It characterizes optical fibre in terms of maximum transmission speed.
d) If a non-monochromatic light impulse is transmitted through an optical fibre, its shape changes along the fibre as a consequence of light wave speed dependence on various factors. The pulse width gradually increases and peak power of impulse is reduced. This fact limits information capacity at high transmission speeds. Dispersion reduces the effective bandwidth and at the same time it escalates the error rate due to an increasing intersymbol interference (ISI). We can analyze this ISI from the eye pattern for different transmission rates . There are three main types of dispersion: modal dispersion, chromatic dispersion and polarization dispersion. We will focus only on one of them – on the chromatic dispersion.

A. Components Of Chromatic Dispersion

The primary cause of the chromatic dispersion (CR) is the fact that different spectral components of the light impulse (different wavelengths) propagate in the optical fibre at different speeds.

As the consequence of different speeds the light impulse spectral components have different time of arrival to the end of fibre, impulse width increases and inter-bit spaces narrow . The receiver cannot correctly recognize whether a transmitter in a specific bit interval sent a value

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of logical one or zero. The distortion of the transmitted information will then increase the bit error rate.

The chromatic dispersion consists of two components:

i. material dispersion
ii. waveguide

The material dispersion is caused by the dependence of the refractive index of the material used for fibre manufacturing where as waveguide dispersion is caused by boundary condition at the fibre surface which are influenced by geometrical parameters of the fibre .The geometrical parameters are mainly: the transversal profile of the refractive index and of the fibre core radius to the signal wavelength ratio. Consequently, the waveguide dispersion affects the speed of light passing through the fibre

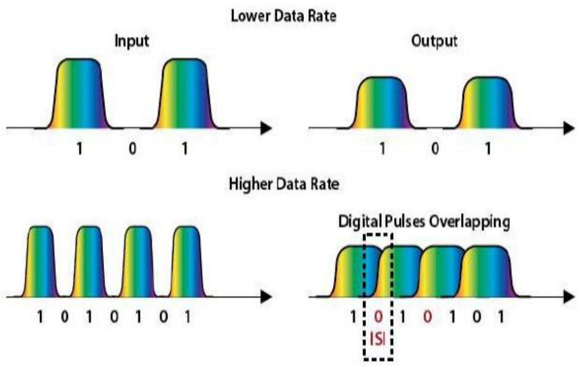

Fig. 1 -The dependence of pulses over lap on transmission rate

B. Parameters of Chromatic Dispersion(CD)

The chromatic dispersion coefficient is a primary parameter. It determines the size of the CD. It is defined by the equation

$$D(\lambda) = \frac{dt_g(\lambda)}{d(\lambda)} \cdot \left[\frac{ps}{nm \times km}\right]$$

Chromatic dispersion coefficient D(λ) expresses group delay tg per km of the signal change per wavelength. The value of the chromatic dispersion coefficient D(λ) is numerically equal to the Gaussian pulse (in ps) of an initial spectral half-width of 1nm width expansion after passing the fibre of a 1 km length. Pulse width increases with:

i. an increasing coefficient of chromatic dispersion D(λ)
ii. a spectral width of the light source
iii. a length of the optical fibre

A typical wavelength dependence of the chromatic dispersion coefficient D(λ) for a conventional single-mode fibre is shown in the Fig. 2.

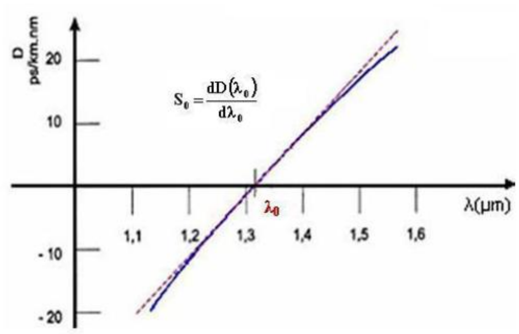

Fig. 2 - The wavelength dependence of the chromatic dispersion coefficient

The image also shows that at longer wavelengths the coefficient of the chromatic dispersion D(λ) is positive, i.e. the light components with longer wavelengths are delayed in the fibre comparing to those of the shorter wavelengths. The coefficient of chromatic dispersion D(λ) for a particular wavelength is calculated using the graph in the Fig. 2 and the following equation

$$D(\lambda) = \frac{S_0}{4} \times \left[\lambda - \frac{{\lambda_0}^4}{\lambda^3}\right] \cdot \left[\frac{ps}{ps \times km}\right]$$

where all parameters are apparent in the Fig. 2.

The chromatic dispersion coefficient at wavelength 1550 nm is cca D(λ)=18 [ps.nm-1km-1].

III. CHROMATIC DISPERSION INFLUENCE ON TRANSMISSION SYSTEM

The transmitted optical pulse extension Δt at the end of an optical fibre is given by the

$$\Delta t = D(\lambda)\Delta\lambda L, \ \left[ps: \frac{ps}{nm \times km; nm; km}\right]$$

where:

Δλ = spectral half width of the transmitted pulse source (LED diode Δλ = 1 nm)

L= fibre length

At the higher transmission speeds it is necessary to use narrower light pulses with shorter spaces (see the Fig. 3). The chromatic dispersion in this case is a very strongly

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limiting factor of the transmission. The chromatic dispersion influences the use of appropriate sources of optical signal.

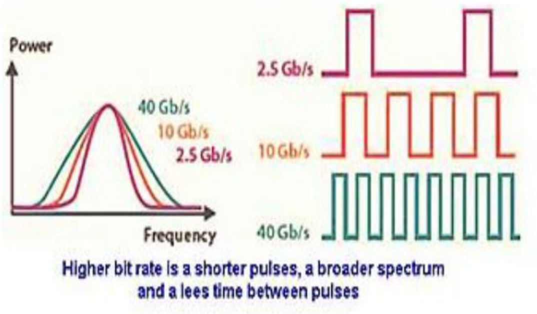


Fig. 3 - Effect of increasing the transmission speed on pulse width and the width of the bit space (1)

The fibre without influence of chromatic dispersion (safe length) we can determine using the following equation

$$L = \frac{1000k}{BD(\lambda)\Delta(\lambda)}$$

Where

k … is a constant of resistance against the spread of impulses (k = 0,5 for the expansion of ½ bit interval)
B … is the signal transmission speed (Gbit/s)
D(λ) … is the coefficient of chromatic dispersion
Δλ … is the a spectral half width of the transmitted pulse source (Δλ = cca1 nm for LED diode)

If we use a wavelength 1550 nm and LED as the light source the safe length (L) is only 22 km for transmission rate B=2.5 Gbit/s and only 5.5 km for transmission rate B=10 Gbit/s. These distances are too short.

So we can change a source and instead of the LED we use a DFB laser with an external modulator based on the principle of Mach-Zehnder interferometer.

This greatly reduces the spectral half width of the light source. It will be considerably smaller than the spectral width of modulation of the transmitted signal, B >> Δλ. A length of fibre without the influence of chromatic dispersion can be determined from the equation now

$$L = \frac{104000k}{B^2 D(\lambda)}, \ \left[km; \frac{Gbit}{s}; \frac{ps}{nm \times km}; nm\right]$$

The maximum distance without interference of the chromatic dispersion increases to 924 km (for bit rate B=2,5 Gbit/s) and to 58 km (for bit rate B=10Gbit/s). Unfortunately, the safe distance decreases with quadrate of the transmission speed.

IV. CHROMATIC DISPERSION COMPENSATION

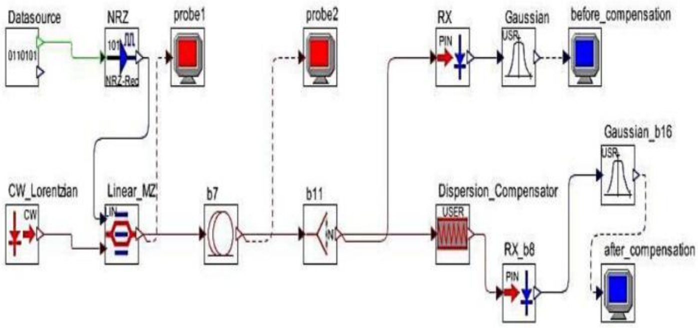
Various methods allow for compensation of the chromatic dispersion. We have already described the possibility of the chromatic dispersion influence reduction using DFB laser diode as a suitable source of the optical signal. The chromatic dispersion comprises the material and the waveguide dispersion. The material dispersion is constant, but waveguide one depends on the fibre geometrical parameters (in the cross section). The manufacturers can modify a refractive index profile so as to set the zero chromatic dispersion coefficient at the desired operating wavelength λ0 (for instance at 1550 nm

Another way to reduce chromatic dispersion is the application of an optical fibre with a high negative chromatic dispersion coefficient DCF (Dispersion Compensation Fibre). The DCF is then a part of a total fibre length usually of about 1/6 of the whole length of the fibre. DCF compensates delays of individual light impulse components at different wavelengths. These fibres have relatively high attenuation (about 0,5dB/km) and are susceptible to effects of nonlinear phenomena

We can reduce the chromatic dispersion by means of Bragg grating, but only for a narrow spectral region (6 nm).

V. SIMULATION USING OPTSIM SOFTWARE

A. Dispersion compensation using Fiber Bragg Grating(FBG)



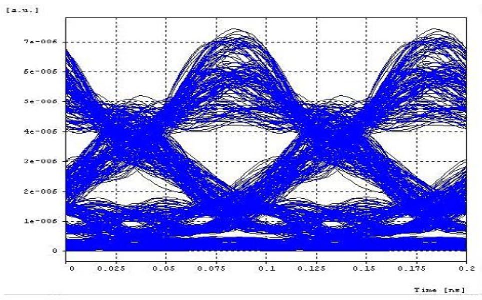


Fig. 7 - Eye diagram before compensation

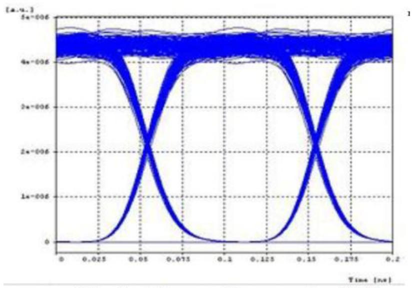
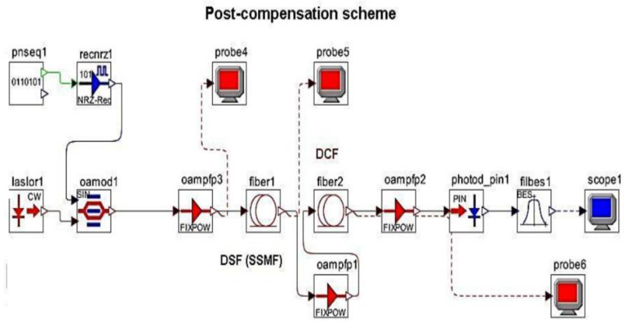


Fig. 8 - The eye diagram after FBG

B. Dispersion compensation using dispersion compensation fiber (DCF)



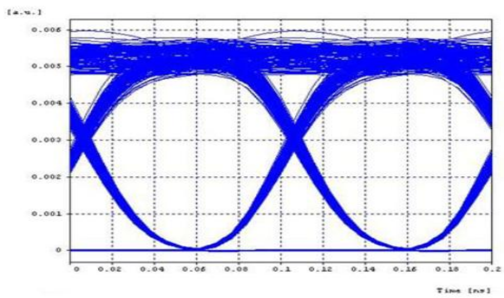


Fig. 10 - Post-compensation DCF eye

VI. CONCLUSION

The aim of this study was to describe the methods of the chromatic dispersion reduction in a classic single-mode optical fibre SMF at a transmission speed up to 10 Gbit/s and to illustrate it using simulation on the OptSim software.

There were performed two simulations – 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 and Q parameters of the two mentioned compensation methods shows that the FBG is the better method for chromatic dispersion compensation than the DCF. Further, on the DCF shows a higher attenuation, which must be compensated by optical amplifiers and so this method is less applicable than the compensation using FBG.

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