Dispersion Compensation for High Speed Optical Fiber Transmission System

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Abstract: The dispersion compensation research includes mainly the following technologies: negative dispersion fiber, chirped fiber grating, prechirped technique, dispersion-supporting transmission, frequency spectrum reversaland soliton transmission and so on. In comparison with those methods and their features, we think the dispersion compensator with chirped fiber grating has its own advantages and is practical.

Key words: dispersion, dispersion compensation, negative dispersion fiber, chirped fiber grating, prechirped technologies, dispersion-supporting transmission, frequency spectrum reversing, soliton transmission.

1. Introduction

It is well known that two main factors limiting the capacity of the optic fiber communication are the loss and dispersion. Since EDFA was successfully developed and applied to the communication system, the loss has been unimportant, but dispersion has become the first important. The research of dispersion compensation of the fiber has become one of the chief subjects to realize the optical fiber communication at ultra-long distance and ultrahigh speed..

Recently, a lot of schemes, such as negative dispersion fiber, chirped fiber grating and so on, have been proposed. They have different physical mechanism, technique and achieving methods. So it is necessary to find the best way which is not only used widely but also upgraded easily.

2. Dispersion in high speed SDH optical fiber transmission system

When an optical pulse signal is transmitted in high speed optical fiber transmission system, it will be dispersed by different group velocities from its various frequencies or modes. It results in the width expansion of the pulse signal and intensity reduction. When the width expanded by dispersion is 0.3 times as many as that of the input pulse, the sensitivity of the receiver rapidly decline and the equalization of the signal becomes very difficult. The error code rate increase greatly. In order to ensure the high quality of transmission, the code space has to be increased. Moreover, the dispersion will also become worse along with the increase of the transmission distance. So the relay distance has to be reduced. Theoretical analysis shows that when communication system operates regularly, there is a critical transmitting radio $B_{cr}=1/4\sigma(W/\alpha)$ and the biggest relaying distance is $L_{max}=C/2DB^2\lambda^2$ (where σ is an average square root of expanded width of optical pulse). Thus, taking appropriately dispersion compensation, reducing even to counteracting the influence of the σ、D, we can optimize B_{cr} and L_{max} and obtain a good communication quality.

3. A few of main technologies on dispersion compensation

So far, the formed dispersion compensation methods, including negative dispersion fiber, chirped fiber grating, soliton transmission, prechirped technique, dispersion supporting transmission, frequency spectrum reversal, multi-voltage code (or multi-levels), coherent light detection, integrated Mach-Zehnder interference, equalizer with fiber delayed line etc, have been widely developed. Here we will research some main schemes of dispersion compensation.

3.1 Negative dispersion Fiber

The fiber dispersion is associated with its material, imparity-doped density, size of fiber core, fiber structure and so on. Changing the fiber structure parameters such as reducing diameter of fiber or various impurity-doped density, we can increase the fiber refractive index and move the zero-dispersion wavelength to 1.55μm or more than it. Thus a bigger negative dispersion fiber (called the dispersion shift fiber) is obtained. We studied the relation between the distribution on refractive index of fiber and the capability of dispersion compensation. A result is that the dispersion of three-clad type of fiber is bigger than that of step or W refractive index type. A quality factor (the rate of the dispersion to loss in the fiber) is introduced to describe the capability of dispersion compensation for the negative dispersion fiber.

The theoretical and experimental results show that the negative dispersion fiber is flexible, convenient and reliable to use because it is a passive device and can be put in any place of transmission network. It is more beneficial to update and increase the capacity of fiber transmission network due to having enough bandwidth. Its weakness lies in expensive cost of fiber and the influence from nonlinear effects when the transmitting speed and distance are further increased.

3.2 Chirped fiber grating

. When an optical pulse goes through a chirped fiber grating, the components of the longer and shorter wavelength of source will be respectively reflected at two different positions in the grating. Thus an optical path of shorter wavelength components is 2Lg longer than that of longer ones. The time delay produced by the two groups of components having different group velocity can be written as $\Delta\tau$=2Lg/Vg. So the chirped fiber grating may be used to compensate dispersion and compress the pulse.

The capability of dispersion compensation of the chirped fiber grating depend on its parameters including the grating length, chirped amount, Bragg bandwidth and character of reflection spectrum etc. The cascaded fiber gratings can greatly increase their capability of dispersion compensation. Thus it is a key for realizing dispersion compensation to design and to fabricate the chirped fiber grating having good quality.

The research results show the technique of chirped grating has many advantages of low loss, small volume, great capacity and good selectivity to wavelength, convenient to use and to upkeep, and easy to integrate. In addition to those, it is not sensitive to polarization and nearly independent of nonlinear effect. So the method of dispersion compensation is also more economical and practical.

3.3 Prechirped technique

In the optical fiber transmission system, dispersion makes the higher frequency components of a pulse signal gradually concentrate to the front edge of the pulse, the lower ones to the back one of the same pulse. The time duration between these two parts is increased so that the pulse width is expanded. Prechirped technique is to apply a sinuidal modulation to an optical source in the intensity modulation and direct detection (ID/DD) system. Its aim is to exchange the frequency distribution on the front and back edge of the pulse. After the pulse is transmitted at a distance, the frequency distribution is recovered to initial state. Thus the dispersion at a certain distance can be compensated. The technique don't need to change the configuration of the transmitter and the receiver, but a extra sinuidal modulator to light source is needed. It is necessary for the lasers to have the better property of frequency modulation. Prechirped technique is mature and has certain upgrade capability.

3.4 Dispersion supporting transmission

The scheme of dispersion supporting transmission adopts the modulation frequency of laser. In the optical fiber transmission system, the signals of the different frequency components transmit at different speeds. When the modulated frequency is appropriately controlled, the time delay difference from the light transmitted at a distance L is $\Delta\tau = \Delta\lambda DL = 1/B$ (where B denote the transmitting ratio of the signal). It makess the frequency modulation signal be changed into the amplitude-modulated. So a recovered initial signal can be obtained by judging from a low-pass filter.

The technique of dispersion supporting transmission has the advantages of the simple structure and lower cost. But it is necessary to use the lasers having good frequency property and to design reasonably the filter.

3.5 Frequency spectrum reversal

When an input signal including the frequencies ω_1, ω_2 and ω_3 (their wavevectors are k_1, k_2 and k_3 respectively) is strong enough, the three-order nonlinear polarization effect occurs. When the condition of phase matching $\Delta k = k_i + k_j + k_k + k = 0$ is satisfied, the four-wave-mixed effect is produced. The frequency of output light is $\omega = \omega_i + \omega_j + \omega_k$ (where i, j, k=1,2,3 and $j \neq k$). If the signal (frequency being ω_s) goes through a certain distance and has certain dispersion, the pump light (frequency being ω_p) with higher power is added to the system. It is necessary to keep the phase matched condition so that to produce a new frequency component $\omega = 2\omega_p - \omega_s$ which can exchange the higher and lower components of ω_s into the lower and higher one of ω, respectively. For the lightwave transmitted continuously, its phases going ahead originally will gradually fall behind, but the original and backward phases will catch up. Thus the original dispersion will gradually reduce until counteract.

The researches show that the frequency spectrum reversal can realize the dispersion compensation in the system having the bigger capacity and longer transmission distance. The loss introduced by it is littler. The semiconductor device can used to realize four-wave-mixed. But it has additional requirement for the large power pump source. So the technology related to frequency spectrum reversal will be studied further to realize the dispersion compensation.

3.6 Optical soliton Transmission

The optical soliton transmission is to use 3rd order nonlinear effect of fiber and can used on dispersion compensation. When the optical energy in the fiber is large enough, it will lead to self-phase modulation which is just contradict to the dispersion of fiber. It keeps the original width of the optical pulse during the transmission. So the soliton transmission is formed. Usually the nonlinear Schrodinger equation is used to resolve the dispersion compensation in the optical soliton transmission.

The optical soliton transmission system isn't used widely for compensating dispersion because of its expensive cost and premature technologies. By the combination of many dispersion compensation methods, the optical soliton communication system can be updated and obtain the efficient dispersion compensation. So it is useful for the ultralong distance and ultrahigh speed optical fiber transmission network and all optical network. It is no dubious that it is an important trend for the future optical communication system.

4 Conclusion

By Analyzing and comparing the performance of the six main dispersion compensation methods, we conclude that: chirped fiber gating can provide the long compensation distance and its cost is lower; the method of negative dispersion fiber is easy to upgrade the system but needs to pay high cost; frequency spectrum reversal can also provide the long compensation distance but is now a premature technology; Prechirped technique has certain upgrade capability but needs the lasers having the better property, the method of dispersion support transmission is of low cost but its upgrade capability is poor. The optical soliton transmission can upgrade system but needs the novel system structure .In a word, the chirped fiber grating has the more advantages: it is easy to be used and has good compatibility with the optical fiber, It is not sensitive for the polarization and the nonlinear effect. Because its fabrication technology is matured, it is convenient to integrate optical devices and to realize all optical system. So it has a wide application prospect. These above methods after further and practically studying can show their advantages in the future development of optical communication system and its dispersion compensation technologies.