Method Analysis of Compensating Polarization Mode Dispersion in Optical Fiber Communication System

Changjingzi Liu *

Department of Communication and Information Engineering, Century College, Beijing University of Posts and Telecommunications, Changsha, Hunan, 410000, China

* Corresponding author's e-mail: 1343113709@qq.com

Abstract. At present, optical fiber communication systems are developing in the direction of large capacity, high speed, long distance, etc., making nonlinear effects and polarization mode dispersion (PMD) and other optical fiber performance defects that were negligible for low-rate systems become the main factors limiting system upgrades and transmission distances. Polarization mode dispersion is an important factor affecting the performance of optical fiber communication systems, and it has become one of the main obstacles to the development of high-speed and long-distance optical fiber communication systems. It can cause pulse widening in the digital transmission system, thereby limiting the transmission rate of the system. Therefore, the influence of polarization mode dispersion on the transmission system and the compensation method are analyzed in this paper.

Keywords: Polarization Mode Dispersion; Compensation Method.

1. Introduction

1.1 Background of the Topic

The development process of communication is to continuously increase the carrier frequency to expand the communication capacity of the process, optical frequency as the carrier frequency has reached the upper limit of the communication carrier, because light is a very high frequency electromagnetic wave, so the use of light as a carrier for communication capacity is very large, is a thousand times the past communication mode, has great attractiveness, optical communication is the goal that people have long pursued, but also the inevitable direction of communication development.

Optical fiber communication system is a communication system that uses light as a carrier, uses extremely pure glass to make a very fine optical fiber as a transmission medium, and uses light to transmit information through photoelectric transformation.

Compared with the previous electrical communications, the main difference is that there are many advantages: it transmits frequency bandwidth, large communication capacity; low transmission loss, long relay distance; thin wire diameter, light weight, raw materials for quartz, saving metal materials, conducive to the rational use of resources; insulation, anti-electromagnetic interference performance is strong; also has strong corrosion resistance, strong radiation resistance, good circumvention, no electric spark, small leakage, strong confidentiality and other advantages.

1.1.1 Background and Significance of Polarization Mode Dispersion Research

Large-capacity (ultra-high-speed and ultra-long-distance) light wave transmission systems and networks bring many unavoidable effects, such as optical fiber losses, various dispersions, etc.

Polarization mode dispersion is caused by the degeneracy of the two quadrature polarization modes of single-mode fibers in practical applications being broken, so that the transmission speeds of the two modes are no longer equal. Therefore, PMD distorts and distorts the signal in the analog system, and the pulse is widened in the digital system, resulting in errors, which greatly limits the transmission of ultra-high bit rates in long-distance optical fiber systems with optical amplifiers.

In order to mitigate the impact on the system, we must find appropriate suppression measures in order to greatly improve the performance of the system. Although the coefficient of the fiber produced has been greatly reduced, and the cost of the fiber itself has become very cheap, the cost of laying new fiber is very high. Therefore, in order to reduce the operation and maintenance costs of the entire system, we must study the suppression technology in order to make full use of the existing optical fiber and gradually upgrade and replace the system.

2. Basic Theory of Polarization Mode Dispersion

2.1 Concept of Polarization Mode Dispersion

There are both internal and external factors that cause the fiber to produce polarization mode dispersion. Intrinsic causes are birefringence between the fiber and cladding produced during fiber fabrication, process defects, uneven internal stresses, and so on. External factors refer to external stresses and environmental changes that bend, deform and age the optical fiber. Due to the influence of these two reasons, the two polarization modes propagate at different rates, and the time to reach the receiving end is different. The differential group delay (DGD) of the two polarization modes is defined as the polarization mode dispersion.

The cross-section of an ideal fiber is perfectly circular and has a circular symmetrical refractive index distribution, whereby the two quadrature polarization modes in a single-mode fiber are completely two-degree degeneracy. Due to the anisotropy in material, shape and stress, the group delay difference between the two polarization modes during transmission is generated, which is the polarization mode dispersion. PMD is caused by the following factors: the inherent birefringence of the optical fiber, that is, the irregular geometric size generated by the optical fiber in the production process and the residual stress in the optical fiber lead to the anisotropy of the refractive index distribution; the optical cable in the process of laying and use, due to the influence of external extrusion, torsion and environmental temperature changes and the polarization mode coupling effect, thereby changing the propagation constant and amplitude of the two polarization modes, resulting in PMD.

2.2 The Cause of Polarization Mode Dispersion

The so-called PMD refers to the characteristics of different group velocities of light in different phase states due to the random birefringence of optical fibers. Polarization is the light performance related to the direction of vibration of light, we know that light in single-mode fibers only the base mode HE11 is transmitted, if the structure of single-mode fiber is ideal cylindrical and the material is isotropic, the refractive index of the two beams of birefringent light in the axial transmission of the fiber is unchanged, then the mode of the polarization state in the two orthogonal directions will not be coupled to each other, single-mode fiber can ensure single-mode transmission, that is, the polarization mode transmission that can maintain the quadrature of the two polarization states, then PMD = 0.

However, in the process of actually manufacturing optical fibers, due to process reasons, the actual structure of the optical fiber will deviate from the ideal cylindrical shape, and there are differences between the non-roundness of the fiber core and the geometric size of the cladding, and the refractive index distribution of the optical fiber is difficult to ensure idealization (completely symmetrical along the radial distribution), so that the optical fiber has anisotropy. In addition, in practical applications, optical fibers are also inevitably subjected to external stresses such as side pressure, twisting force, and bending force. These factors will cause the birefringence of the optical fiber, so that the two polarization modes of HE11 cannot be completely merged, resulting in a polarization instability.

2.2.1 Birefringence

Birefringence is the root cause of polarization mode dispersion. Birefringence is further divided into two categories: intrinsic birefringence and non-intrinsic birefringence.

Intrinsic birefringence is mainly accidentally introduced in the production process of optical fiber, resulting in the non-roundness of the optical fiber and the asymmetric gravitational field caused by the uneven doping concentration around the core, in addition, the fiber core, cladding and other doped materials that make up the fiber lead to different coefficients of thermal expansion, so that the optical fiber stretch cooling produces radial stress, the uneven stress is converted into the uneven refractive index, and also causes the generation of birefringence.

Non-intrinsic birefringence is divided into bending, external stress, torsion, electromagnetic field and other birefringence, which is caused by the formation of optical fibers, cable laying and environmental changes.

2.2.2 Mode Coupling

Since the birefringence produced by the optical fiber is randomly changed along the entire optical fiber link, the energy of the two polarization modes is constantly exchanged during the optical pulse transmission process, resulting in random mode coupling, and it is obvious that the emergence of this effect is conducive to attenuation. In the theoretical study, the coupling is divided into strong coupling and weak coupling, corresponding to long fiber and short fiber, respectively. For long fibers, it is proportional to the square root of the distance, and for short fibers it is proportional to the distance. The mode coupling changes over time, and the reason for this is that the environment around the fiber optic cable is always changing.

3. Compensation Technology for PMD

With the new development in recent years, after the system capacity of optical fiber communication reaches 10Gbit/s and above, PMD has become a new limit on the capacity of optical fiber communication system. Therefore, PMD must be compensated to increase the transmission capacity of the optical fiber communication network and increase the transmission distance without electric trunking. The essence of the scheme of compensating for PMD is to compensate for the delay difference between the two polarization modes caused by PMD by using some optical or electrical delay line. The principle is: first separate the two polarization mode signals on the optical or electrical, and then compensate them for the delay with the delay line, and under the control of the feedback loop, the delay difference between the two polarization modes is zero. Finally, the compensated two polarization mode signals are mixed output. Depending on the device that makes up the PMD compensator, PMD compensation can be divided into electrical domain, optical domain, and photoelectric combination compensation.

3.1 Electrical Domain Compensation

Electrical compensation technology is the earliest compensation technology used, the principle is mainly based on the equalization of the plastic signal in front of the receiver, the method is to receive the optical signal, turn it into an electrical signal, and then control it through the compensation judgment circuit. First of all, the optical signal from the transmitter enters the polarization controller after passing through a period of high-polarization fiber, and the light coming out of the polarization controller is decomposed into a polarization mode and a polarization mode, and then, the two basic polarization modes are sent to the optical receiver and the optical receiver respectively, converted into an electrical signal, and the fast signal delay compensation is used by the delay circuit, and the last two signals are mixed and output together.

3.2 Optical Field Compensation

Since the electric domain compensation is inevitably limited by the "bottleneck" of the electron rate, the current field of optical domain compensation research is more active, and it is also the most likely solution to solve the PMD of systems above 40Gbit/s and can be practical. A complete optical field compensator device basically consists of three parts: a compensation unit, a feedback signal, and a control unit. The figure 1 shows a schematic diagram of the polarization mode dispersion compensation structure. Optical field compensation is the insertion of optics into the optical fiber transmission link to control the polarization state of the light and adjust the delay, thereby realizing PMD compensation.

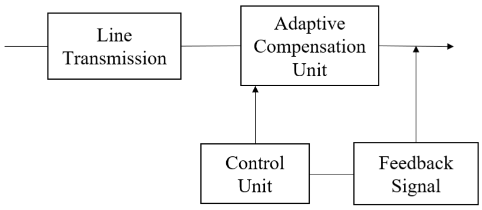

Figure 1. Schematic diagram of PMD compensation structure

This method can compensate for different adjustments, is compatible with optical fibers, and is small in size and large in compensation.

3.3 Photoelectric Bond Compensation

It is a joint scheme of combining light and electricity and compensating for electrical signals. First, the optical signal with PMD effect is decomposed into two basic polarization modes PSP1 and PSP2 through the polarization splitter (PBS), which are received by two optical receivers and converted into electrical signals, and the faster signal is compensated for delay in the current domain (B), and finally the two signals are mixed (A+B) output. Among them, the role of the polarization controller (PC) on the optical path is to adjust the direction of PSP1 and PSP2 and their splitting ratio; the role of phase difference detection is to achieve control of the polarization controller (PC) and the amount of electrical signal delay (Δτ). The compensation schematic is shown in the figure 2.

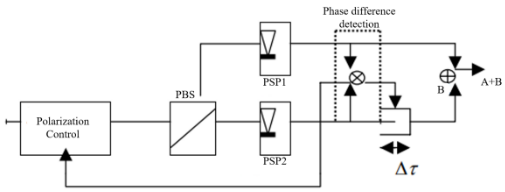

Figure 2. Photoelectric Combined Compensation Schematic

4. Conclusion

This article does some analysis and discussion of PMD and its compensation techniques. From the discussion, it can be concluded that the choice of compensation scheme should be based on the specific requirements of PMD compensation.

At present, with the rapid development of the information industry, bandwidth pressure is an unprecedented challenge for the backbone transmission network, and it is evolving towards a high-capacity optical transmission network with high speeds of 10Gb/s, 40Gb/s and even 100Gb/s. With the rapid development of microelectronics technology and digital signal processing technology, the electronic dispersion compensation technology has once again had a wide performance stage. The complexity problem in the optical domain is converted to the lower-cost realizable electric domain, and a variety of digital signal processing algorithms are used to compensate, reducing the dependence of the transmission system on optical fiber links and optical devices; it is conducive to the photoelectric integration and miniaturization of the system, and creates a new era of optical fiber communication system transmission.

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