Research on Efficiency Improvement Strategy of Optical Fiber Signal Transmission Based on Fourier Transform

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Abstract. With the continuous development of society, optical fiber communication system has become a necessity in people's life. Although the loopholes of the system are gradually improved, there are still many factors that affect the performance of the signal transmission in the actual transmission process. Compared with the traditional Fourier transform, there are some new transforms, such as fractional Fourier transform and DFT-S. These new transformations can observe, analyze and process signals more completely and concretely. Through which the signal can be transformed into the domain and more information of the optical fiber signal can be obtained.

Keywords: Optical Fiber Signal Transmission, Fourier Transform

1. Optical fiber signal transmission

1.1. The principle of optical fiber signal transmission

Optical fiber transmission system mainly contains transmitter, optical amplifier relay equipment and receiver. The noise that reduces the signal-to-noise ratio of the receiver is mainly the ASE noise generated by the optical amplifier, which is also the main noise source of the low-energy optical fiber channel, so the processing of ASE is particularly important. The commonly used optical fiber model approximately regards the ASE noise as the superposition of two white Gaussian noises and the optical communication system as the additive white Gaussian noise (AWGN) channel. The probability distribution of ASE noise is chi-square distribution with non-Gaussian and asymmetry\cite{1}.
1. Factors affecting the performance of optical fiber signal transmission

Optical fiber communication has made great progress in recent decades. The development of many emerging services requires optical fiber communication systems to provide higher transmission rates and longer relay distances. In the ultra-long-distance and high-capacity optical fiber communication system, the performance of the system is greatly degraded because of the interference factors such as dispersion, fiber loss and nonlinear effect. The main influencing factors are as follows:

1.2.1. Polarization mode dispersion (PMD)

For optical fiber communication systems with a transmission rate of 10 Gbit/s and higher, the influence of PMD is more significant, which limits the signal transmission and affects the whole transmission performance. Ideally, the cross section of the optical fiber should be standard circular, and the size of the cross section and the distribution of refractive index are uniform everywhere.

However, there are always some imperfections in the actual optical fiber:

1. Optical fiber has ellipticity.
2. There is residual stress inside the optical fiber.
3. In the practical application of the traditional optical fiber spectrum communication algorithm, because of the difference in the material density of the optical fiber, the coupling between polarization and differential group delay is poor. The running speed of the polarizer is much higher than that of the differential group delay, which makes the signal receiving spectrum error and reduces the accuracy of the spectrum. These reasons lead to birefringence in the fiber, making the polarization modes touch the end of the fiber at different moments, creating a difference of group delay. This is PMD, which is proportional to the square root of the length.

PMD will cause large pulse broadening and the decrease of optical signal-to-noise ratio (OSNR). Therefore, PMD must be strictly controlled in the stages of system design, construction, acceptance testing and so on.

There are many compensation measures for PMD. For the newly built high-speed optical fiber transmission system, the optical fiber with strict manufacturing process and good PMD index can be selected. In order to upgrade and expand the capacity of the original line, the compensation of PMD must be considered. Generally speaking, these methods can be divided into two types: electrical domain compensation and optical domain compensation. Due to the limitation of the working rate of electronic devices, the response rate of electrical domain compensation is restricted. Optical domain compensation is relatively more popular among researchers. Birefringent fiber grating is a promising compensation scheme[2].

1.2.2. Performance changes caused by different modulation methods

PSNRZ modulation and DQPSK modulation are generally considered to be the two most potential
modulation technologies in the next generation optical fiber communication system. All of them can meet the requirements of dispersion and nonlinear effects in 40 Gb / s high-speed optical fiber communication system.

The principles of the two modulation methods are very different. PSNRZ modulation is to make the pulse have a compression process in the initial stage of entering the optical fiber, so as to alleviate the pulse broadening caused by dispersion. The DQPSK modulation adopts the quaternion method, which reduces the link performance requirements of the system by halving the symbol rate under the same information rate.

Compared with the separate transmission of the two systems, the system performance of hybrid transmission is significantly worse, and the deterioration of DQPSK system performance is more obvious [3].

1.2.3. Laser Phase Noise (LPN) [4]

The influence of LPN on the performance of coherent optical fiber communication system is related to RS: the smaller the RS of the system, the more serious the phase noise of the same laser. In other words, the low-speed system has more stringent requirements on LPN. This is the difference between LPN and other transmission damages.

Even though the larger the RS, the less the impact of LPN, for the sake to cut the requirements for other devices, in fact, coherent optical fiber communication systems always try to use high-order modulation format, so that RS can be reduced. As a result, LPN is still the major factor which restricts the performance of coherent optical fiber communication systems with high bit rate.

2. The principle of the Fourier transform

The real Fourier progression represents the superposition of any function into an infinite number of sine waves of different amplitudes and frequencies.

\[ f(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} (a_k \coskwot + b_k \sinkwot) \]

Sound waves can be decomposed into the tonal components of different frequencies through FT. Each tonal component of which is expressed by a sine wave whose amplitudes and phases are different.

Spectrum is short for frequency spectral density, which is a distribution curve of frequencies. Complex oscillations decompose into resonant oscillations of different amplitudes and frequencies, and the graph of these resonant oscillations arranged by frequency is called the spectrum. What is commonly referred to as the frequency domain actually refers to the frequency spectrum. So, do the multiplication of the signal in the time domain can be equated to the convolution of the signal frequency domain.

In the above equation, \( f(t) = s(t) \) when \( k = 1 \) and \( a0 = 0, \ a_k = a, \ \text{and} \ b_k = -b \). Thus, the process of modulation is the multiplication of the Fourier coefficients and the sine cosine signal to produce a new signal to send. Demodulation is the process of solving the Fourier coefficients, which means that the modulation and demodulation of a signal is a simple application of the Fourier transform.

3. Improving fiber optic signal transmission performance based on Fourier transforms

3.1. Current status of Fourier transform applications in the field of signal transmission

Since 1807, when French scientists first proposed Fourier analysis, the Fourier transform method has been widely used, playing an important role in almost all fields of scientific research and engineering technology.

With the expansion of the object of study and the scope of research, the limitations of the Fourier transform in dealing with certain problems are gradually exposed. Such limitations are mainly reflected in: It is a global transformation that yields the entire spectrum of the signal, and thus it
cannot express the local time-frequency characteristics of the signal, which are the most fundamental and critical properties of an unsteady signal.

To address these problems, a number of new signal analysis theories have been proposed and developed, including the fractional Fourier transform, Winger distribution, Gabor transform, wavelet transform, and AM-FM signal analysis. Among them, researchers prefer the Fractional Fourier Transform (FrFT) \(^5\).

### 3.2. Applications of the new Fourier transform

#### 3.2.1. Fractional Fourier Transform

The basic FT is good for analyzing deterministic or smooth random signals. However, for non-stationary signals, some performances need to be accurately described by using a two-dimensional joint representation of the time and frequency domains.

The FrFT links relatively independent time-domain and frequency-domain information and also maps the single-dimensional time-domain signal to a two-dimensional time-frequency plane, which reflects the time-frequency distribution characteristics of the signal over time.

FrFT has been widely used in many areas, including swept frequency filters, ANNs, time-frequency analysis, and multiplex transmission. Moreover, it has more extensive applications in solving differential equations, optical image processing, and many other fields.

When an optical signal is transmitted in an optical fiber, it produces a chirp effect on the signal in the time and frequency domains, respectively, making it a chirped signal. This is a kind of non-stationary signal with large time and bandwidth. Using the traditional signal processing method to analyze it is not ideal.

#### 3.2.2. Multi-band Discrete Fourier Transform Spread Spectrum (DFT-S) technique\(^6\)

The Orthogonal Frequency Division Multiplexing (OFDM) method is one of the main research directions for bulky, long-distance fiber optic transmission systems. The Peak to Average Power Ratio of quadrature frequency division multiplexing leads to high nonlinearity, making it does not perform as well as single-carrier in terms of nonlinearity.

For quadrature frequency division multiplexing system, DFT-S can effectively reduce PAPR and mitigate the nonlinearity effect. This technique can to some extent overcome the inherent shortcomings of fiber optic transmission and achieve similar transmission performance, which is an important technology reserve for future ultra-long-distance fiber optic transmission.

![Figure 2. Signal generation diagram of DFT-S OFDM.](image)

### 4. Conclusion

With the continuous development of fiber optic communication system, for improving the performance of fiber optic system and provide more convenience to people's life, the performance
study of fiber optic communication system based on novel Fourier transforms is an important way to improve the quality of fiber optic communication system. This study summarizes some novel transforms, such as fractional order Fourier transform and DFT-S. These transforms are able to observe, analyze and process signals more completely and specifically and obtain more information about the fiber optic signals.

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