The Study on the Effect Factors of Single-mode Fiber Optical Signal Transmission Time Delay

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Abstract. With the rapid development of communication technology, various communication means and applications emerge in endlessly, the use of the communication system environment is increasingly complex, thus, these systems in complex signal environment simulation and the experiment of the assessment is put forward higher requirements. Optical fiber time delay technology is a kind of signal transmission delay simulation technology, the use of this technology can greatly reduce the cost of related validation and time. Optical fiber delay technology is for communication system; especially the signal transmission of wireless communication system simulation and disturbance simulation provides a highly efficient, low-cost, practical means. It has a good application prospect in civilian and military, aerospace and other fields. This article will mainly analyze the effect of single-mode fiber optical signal transmission delay factors and treatment measures.

Introduction

In the design of radar, communications, electronic equipment to electrical signals are often required long time delay, electrical delay line due to the material size limit is difficult to realize the long time delay, although, in recent years, surface acoustic wave delay line because of its simple structure, small volume features in radar, communication and other electronic system to replace the cable delay line, but because of its frequency band is too narrow, the temperature influence big shortcoming can't satisfy the bandwidth of the complex modulation signal in radar, communication equipment requirements, and difficult to achieve stability of long time delay. Since the 1980 s, the optical fiber transmission technology is the development and wide application of signal transmission delay technology, the application is already very mature at present. Because of its signal transmission is not affected by electromagnetic environment interference, wide bandwidth, delay, the characteristics of the temperature gradient is small, gradually became one of the radio frequency, frequency delay signal more ideal choice.

The principle of optical fiber time delay

The basic principle of optical fiber time delay technology is the use of optical signal after a certain length of optical fiber transmission time delay. Optical signal transmission speed is relatively lower than in quartz medium propagation speed in a vacuum, light travels in a vacuum in the refractive index is 1, and the propagation in the fiber refractive index of about 1.47 (commonly used for g. 652 single mode fiber, under 1550 nm wavelength, often take n = 1.467). Light signals in optical fiber transmission delay time formula is as follows:

$$t = L \times nlv \qquad (1)$$

In the formula, t is for transmission time, L for fiber length, n is as the medium the refractive index, v is to the speed of light in a vacuum.

Optical fiber delay technology using the characteristics of the optical transmission, high anti-interference ability; High bandwidth, high bandwidth can reach 10 Gb/s; Delay time range is large; Commonly used along with the temperature gradient is small, G.522 optical fiber delay temperature coefficient of about 0.05 ns/(km • ℃), basically will not affect the application.

To implement step amount to 50m simulation distance, according to the formula (1) corresponding to the minimum length of the fiber ring is 68.2 m, then each light switch connected by optical fiber loop length were 68.2 * 21 m, 68.2 * 22 m, 68.2 * 23 m, 68.2 * 24 m, 68.2 * 25 m, 68.2 * 26 m, 68.2 * 27 m and 68.2 * 28 m. Such a design can be implemented step by step the amount to 50 m, the range of 0 ~ 16500 m delay distances, including a total of 512 delay distance to choose from. We choose 2 * 2 optical switch, and different amount of time delay of switching is realized by using differential structure design, this kind of optical switch, the average insertion loss about 0.8 dB, because every time delay using the difference structures pathways through the access of the optical switch frequency, the same loss consistency, commonly used in G. 652 fiber loss about 0.2 dB/km, according to the above parameters are calculated, the entire optical path loss is decided by four parts: straight adjustable laser electro-optical conversion efficiency, fiber optic path loss, electro-optic conversion efficiency of photoelectric detector, and the input and output impedance ratio; Can be represented by (2) :

$$G_{dB} = 20\log(\eta_{TX}\eta_{RX}) - L_{opt} + 10\log(\frac{R_{out}}{R_{in}}) \qquad (2)$$

η_{TX} is for straight laser electro-optical conversion efficiency, according to the test η_{TX} is 0.075. η_{RX} is for the photoelectric conversion efficiency of the photoelectric detector, according to the test η_{RX} is 0.65. L_{opt} is the loss for optical fiber access, including the following several parts: the optical fiber transmission loss, insertion loss of optical switch and optical connection head loss; Calculated on the longest fiber length is 22495 m, the largest optical fiber transmission loss of 4.5 dB (standard single-mode fiber loss coefficient of 0.2 dB/km). Each optical switch insertion loss of 0.8 dB, a total of 10 optical switch, so the total insertion loss for the light switch is 8 dB; Each light connector insertion loss of 0.2 dB; Optical link to connect to the light through a total of 20, So the introduction of optical connector loss as 4 dB. So the whole optical link loss L_{opt} is $4.5+8+4=16.5dB$.

The light real-time delay technique

Phased array antenna technology (PAA) since the 1970 s application, with its unique advantages in the field of radar occupy the important position, but the radio frequency electronic beam forming mechanism volume and weight are larger, limits its wide application. Especially in the applications of airborne and space borne, must seek a smaller volume, lighter weight of phased array radar. Since the 1990 s, the Optical True Time Delay (OTTD) fully mature, and gradually be applied optical controlled phased array antenna (OCPAA). The light of the application of optical controlled phased array antenna real time delay technology main technical idea is: the frequency of the electrical signals relative is extremely low, it can be loaded into the light, the light of the load electrical signal delay again, and then to pick up the signal light detector, the electrical signals are extracted with modulation signals in addition on the phase before a certain delay, other features are exactly the same, in this process in real time delay (TDD) system called OTTD system. OTTD based on optical fiber technology is the study of the earliest technical scheme, the traditional optical fiber type OT TD is by choosing a different value of optical path for a number of discrete time delay, transmission path can be divided into fixed path and dynamic configuration type two kinds.

The traditional fixed path type. Optical phase array radar is first proposed in the literature with traditional optical fiber fixed path delay technique. As shown in figure 1, it contains 8 period of specific length of the light source and 8, when working through the gate bias switch configuration one particular light source, electrical signal is modulated on the light source, through a 8:1 photosynthetic breaker send light to light detector, the final recovery out of the electrical signals. Optical difference depends on the length of the antenna aperture and the maximum steering Angle, the separation of 23 delay state just provides 3 bit resolution, the main radiation lobe can be point to any one of eight directions, the more the path of the fiber, and the higher resolution. Obviously, the extensibility of the scheme is bad, can't satisfy large array, high resolution requirements. Light source and the time delay of the path 1:1 configuration are also greatly increased the complexity of

the system, increase the cost of the system. This structure is generally called PADEL structure (Parallel Fiber Optical Delay Line).

Dynamic configuration type. This solution applied more widely, as shown in figure 1, the fixed wavelength laser are electrical signal modulation into optical switch, optical switch, through optical Fiber connection between a number of optical switch with the method of cascade, this is the so-called BIFODEL structure (Binary Fiber Optic Delay Line).

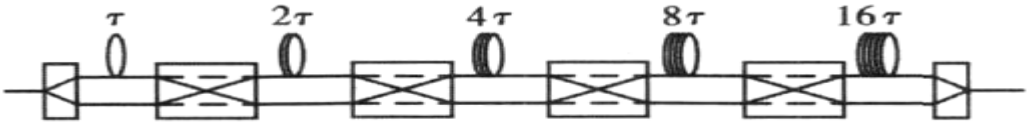

Figure 1: The dynamic configuration type

As shown in figure 1, with a 5 bit OTTD, for example, before and after the two optical switch between two pieces of optical fiber length, respectively τ, 2τ, 4τ, 8τ and 16τ, through the configuration of each optical switch state, 32 different time delay can be obtained.

In this kind of OTTD scheme, topology structure, there are two main ways, one is the difference structure, as shown in figure 1, and the other one is the bypass structure. Delay in bypass structure, fiber optic jumper in the same light switch is a pair of input/output port, the structure is more compact, 5 bit delay units only need 5 only optical switch. In addition, you can add an optical fiber in optical fiber delay, so that the lights switch to compensate the error caused by different state. The disadvantage of this structure is also very outstanding, it is the minimum delay due to structural factors can't be small, and with the need of each optical switch by twice, so the insertion loss is larger.

The effect factors of single-mode fiber optical signal transmission time delay

There is in the reports of the literature, the dispersion element OTTD technology uses is the mainstream, traditional based on delay in optical switch and the structure of the fiber seldom reported. Along with the development of the material, the greater the dispersion coefficient of dispersion components, the smaller the volume and weight of the system, from neglected dispersion optical fiber to the application of photonic crystal fiber in OTTD suggest that this trend. As the FBG, CFG and T LS device technology advances, OTTD indicators, such as the dynamic range of time step length and time delay adjustable will have great progress. In addition, for the waveguide delay line, study more is in front of the discrete delay line structure of optical waveguide, optical waveguide is delay line and the structure of the optical waveguide switch, current research emphasis has begun to shift to the continuous research on optical waveguide delay line. In terms of waveguide materials, because of the waveguide loss is bigger, the future development of is necessarily loss lower waveguide materials.

When the environmental temperature change, has certain influence to the optical fiber, because the fiber is quartz medium, this effect is small, transmission delay temperature coefficient is generally calculated at 0.05 ns/(km • ℃). If the 63.5 km system delay at room temperature (25 ℃), according to the working temperature ±5 ℃ for calculation accuracy, during work, maximum time delay error of the system: 5 ℃ * 63.5 * 0.05 = 16 ns.

When optical transmission to a certain distance to dispersion must be considered if the above system to obtain larger delay, such as the three sets of series, the use of optical fiber up to 190 km, therefore, should consider the fiber dispersion will affect performance of the system.

The design of the optical fiber delay system

The choice of optical switch. Optical switch can be divided into two kinds: one kind is the use of electromagnet or stepper motor driver to realize the light path switching mechanical optical fiber or lens optical switch, another kind is to use solid physical effects (such as lightning, magneto optical and thermal effects of light and sound and light) solid optical switch. Now with mechanical

optical switch technology is mature, in insertion loss and isolation, extinction ratio and polarization sensitivity has good performance, and is not subject to the limitations of the modulation rate and modulation. Main mechanical optical switch are common mechanical optical switch and MEMS, optical switch, the disadvantage of ordinary mechanical optical switch is the switch time (from tens of milliseconds to millisecond level), the size is bigger; MEMS optical switch with fast speed (milliseconds to the millisecond level), small volume, and easy to the advantages of large scale integration, but the cost is relatively high. Specific choose that kind of optical switch should choose according to the actual needs of the system.

The light power calculation and optical amplifier design. System is mainly composed of optical fiber loss, loss of power light switch loss, and loss of fixed attenuator. G. 652 and g. 655 optical fiber loss about 0.20 dB/km, fixed attenuator loss and the corresponding delay the loss of the fiber are equal, 2*2 optical switch is an average of 0.78 dB insertion loss, according to the above parameters are calculated, will arrive at point P light signal from the input of the average light power is: 0 - (6* 0.78 * 0.20 + 0.78) = -17.38 dBm.

If the input power of the optical amplifier choice - 25 ~ -10 DBM, can completely meet the requirements, and has a certain amount of surplus. Optical amplifier has a constant power output and the fixed gain two kinds, theoretically fixed gain of the amplifier to influence than the fixed power output of the analog signal amplifier, in be used actually also proves this point. In order to reduce the noise coefficient of optical amplifier, can increase inside the amplifier ASE filter, thus the output wavelength locking on the wavelength of laser. The system is analog signal transmission; optical amplifier output optical power is best can stay above zero DBM, to make the optical receiver have good effect of demodulation. The output of the amplifier can connect optical receiver, can also cascade and the lower level equipment.

Summary

In this paper, with the optical fiber transmission delay technology, through the reasonable design to achieve the complex debugging applications in radar, communication signal of long time delay system, and this time delay system with high anti-interference and high reliability, large range of delay and bandwidth, the characteristics of high stability, greatly reduces the radar and communication systems related to the cost of testing, validation, simulation and time. With the rapid development of optical fiber technology and process of gradually mature, time delay based on optical fiber transmission system will be more and more widely applied and practical.

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