Research on Testing of Optical Fiber Wavelength Division Multiplexing System

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Abstract. In order to meet the requirement of long-distance high-speed data bus for information transmission in vehicles, optical fiber wavelength division multiplexing (FWDM) technology is used to realize the transmission of multiple optical signals by connector. Although wavelength division multiplexing technology has been widely used in the field of communication, the adaptability of the real-time control system needs to be further studied. In this paper, a prototype of the optical fiber wavelength division multiplexing system is tested and the test results are preliminarily studied, which provides a basis for evaluating transmission reliability margin and analyzing system failure.

1. Introduction

In order to solve the problem of the long-distance transmission of high-speed information in real-time systems, wavelength-division multiplexing technology is used to transform the multi-channel optical fiber paths of long-distance communication nodes into a single optical fiber through the rotary connector, and then the multi-channel optical fiber high-speed communication between nodes is realized by wavelength-division multiplexing and wavelength restoration. Because there are many links in the process of WDM implementation, it is necessary to evaluate the performance of each link and locate the faults. It is necessary to study the testing technology of WDM in the practical application process.

1.1. Optical Fiber Communication Technology

Optical fiber communication is realized by using the characteristics of optical fibers and lasers. It uses the coherence and direction of lasers as the carrier of information to transmit in optical fibers.

Optical fiber communication technology includes the following main parts: optical fiber cable technology, optical switching technology, transmission technology, optical active devices, optical passive devices, optical network technology, wavelength division multiplexing technology and so on. The main components of the optical fiber communication system include optical fibers, optical transmitters, optical receivers, optical repeaters and appropriate interface devices. The basic structure of the system is shown in Figure 1. The function of the optical transmitter is to convert the electrical signal from the user into the optical signal, and then incident to the optical fiber transmission. The function of the optical receiver makes the optical signal transmitted from the optical fiber into the electrical signal, and then sent to the user. The optical repeater is used to increase the transmission distance of light. It transforms the optical signal with greater attenuation and distortion into the optical signal without attenuation and distortion after transmission through the optical fiber, and then continues to input the transmission in the optical fiber.
1.2. WDM Technology

Wavelength Division Multiplexing (WDM) technology makes full use of the huge bandwidth resources brought by the low loss region of single-mode optical fibers. According to the different wavelength of each channel, the low loss region of the optical fiber is divided into several channels. The optical wave is regarded as the carrier of the signal, and the wavelength division multiplexer (Wave combiner) is used at the transmitter. The signal optical carriers of different wavelengths are combined and sent to an optical fiber for transmission. At the receiving end, the optical carriers carrying different signals at different wavelengths are separated by a wavelength division multiplexer (Wave separator). Since the optical carrier signals of different wavelengths can be regarded as independent of each other (without considering the non-linearity of the optical fiber), multiplexing transmission of multiple optical signals can be realized in one optical fiber.

1.2.1 Principle and Key Technologies of Wavelength Division Multiplexing

Typical applications of WDM technology in optical networks are shown in Figure 2. The WDM system consists of an optical multiplexer and an optical demultiplexer which can extract independent optical wavelength. The basic principle is that the optical transmitter at the transmitter sends out optical signals with different wavelength, accuracy and stability satisfying certain requirements, which are combined by OMU and coupled into a single optical fiber for transmission; after reaching the receiver, the optical signals of different wavelengths are decomposed by an optical wavelength selector, and then sent to the receiver.

The key technologies of WDM include combiner/divider and light source devices. The combiner/demultiplexer is an optical filter whose function is to multiplex and demultiplex all optical wavelengths. The basic requirements of involution/demultiplexer are low insertion loss, high isolation, good band-pass characteristics, good temperature stability, multiple wavelengths, high resolution and so on.

2. WDM Optical Fiber Communication Test Project

Referring to the national telecommunications industry standard YD/T 1159 "Test method of optical wavelength division multiplexing (WDM) system" and its practical application, the following tests can be generally carried out for WDM system testing.

2.1. Wavelength Conversion Test

The function of wavelength conversion is to convert the input signal to the output of the wavelength signal conforming to G.692 standard, and to convert the wavelength signal of G.692 standard to the wavelength used by users. For the system, each wavelength converter corresponding to each path should be tested path by path. The test items include receiver sensitivity, overload power, receiver...
reflection, output optical power, center frequency, center frequency offset, extinction ratio, eye chart template and so on.

2.2. Main Optical Channel Testing
In this paper, the main optical channel of the WDM system refers to the channel between the multiplexer of WDM system and the demultiplexer of the receiver. Test items include output/input power per channel, total transmission power, signal-to-noise ratio per channel, maximum path power difference and so on.

2.3. Testing of Optical Wavelength Division Multiplexer/Demultiplexer
The test items include adjacent channel isolation of demultiplexer, the insertion loss of demultiplexer, bandpass characteristics of the demultiplexer, the central wavelength of the demultiplexer and so on.

2.4. Transmission Performance Test
The system performance test is the performance test of WDM system. The test items include system error characteristic test, system jitter characteristic and so on.

3. Test of WDM Communication System Equipment
In this paper, based on an optical fiber transmission the WDM device, some test items and test results of the device are given, and the fault examples in the system are analyzed.

The test object is 8-channel optical fiber transmission WDM device, which is divided into device A and device B as shown in the figure. The two devices are connected by multiplexing optical ports to realize 4-way up-link and 4-way down-link optical signal transmission. In the upstream and downstream channels, there are three channels supporting 3.125G connection rate and one channel supporting 10Gb/s connection rate. The external interface of the WDM device is 850 nm multi-mode optical signal input/output interface, and a single-mode WDM optical signal connection is used between multiplexing devices.

Figure 3. Structural Diagram of the 8-channel WDM System under Test

3.1. Average Emission Power of Wavelength Converter
In this test, the optical power of 850 nm signal emitted from the external interface of the WDM device is tested. The purpose of the test is to detect the optical power value of the optical signal output from the WDM device after wavelength conversion. The test mode is that the output of the external interface optical module is directly connected to the optical power meter, and the optical interface transmits pseudo-random sequence signals. The test rate is 3.125 Gb/s, code type is PRBS 2^7-1, optical power meter is AV6334A.
3.2. Receiving Sensitivity of Wavelength Converter

In this test, the sensitivity of the external interface of the WDM device to 850 nm signal reception is tested. The purpose of the test is to detect the receiving sensitivity of the external optical signal of the WDM device's WDM front-end receiving system. The external interface optical module generates pseudo-random sequence signals from the optical interface of the error detector. By adjusting the size of the attenuator, the received results are connected to the error detector. The attenuator attenuation is gradually increased. When the error occurs, the optical power of the WDM interface measured by the optical power meter is the receiving sensitivity. The test rate is 3.125 Gb/s, code type is PRBS 2^7-1, optical power meter is AV6334A.

Table 2. Average Receiving Sensitivity Rate of 850 nm Module(dBm)

| Equipment | I/O 1A (3.125G) | I/O 1B (3.125G) | I/O 2A (3.125G) | I/O 2B (10G) |
|-----------|----------------|----------------|----------------|-------------|
| Device A  | -14.86         | -14.86         | -15.22         | -8.5        |
| Device B  | -15.45         | -14.86         | -14.66         | -8.5        |

The receiving sensitivity index is "input optical power(3.125Gbps)≤-14dBm, input optical power(10Gbps)≤-8dBm ". The test results meet the design requirements.

3.3. Wavelength measurement of wavelength division multiplexing

After different wavelength signals from wavelength converter pass through WDM, the multi-channel optical signals are combined to a single optical fiber, and the wavelength is measured by a wavelength meter.

In order to measure the influence of temperature on the wavelength of the output signal of the WDM optical module, the wavelength of the output signal at three temperatures was tested. The measured WDM devices are placed in high and low temperature chambers, and the test temperatures are -43°C, 20°C and 60°C respectively. The test equipment is Agilent 86120B multi-wavelength meter. The test results are shown in the table below.

Table 3. Wavelength Converter CWDM Module Emission Wavelength Value

| Nominal central wavelength nm | Measuring wavelength value nm |
|------------------------------|--------------------------------|
|                              | -43°C  | 20°C  | 60°C  |
| 1310                         | 1304.116 | 1310.581 | 1313.324 |
| 1330                         | 1324.287 | 1333.537 | 1333.289 |
| 1470                         | 1463.935 | 1471.000 | 1473.909 |
| 1490                         | 1483.846 | 1490.640 | 1493.648 |
| 1510                         | 1502.933 | 1510.261 | 1513.244 |
| 1530                         | 1525.289 | 1532.007 | 1535.082 |
| 1550                         | 1543.328 | 1551.111 | 1554.413 |
| 1570                         | 1564.297 | 1571.172 | 1574.279 |
The wavelength design index is "central wavelength (±7 nm)", and the test results meet the design requirements. From the test results, it can be seen that the wavelength of the WDM light source is affected by ambient temperature and distributed on both sides of the intermediate wavelength.

3.4. System Error Characteristic Test
In the practical application of the system under test, the transmission content of the 1490nm channel is often abnormal. Therefore, it is necessary to analyze the cause by detecting the error code. The system error code test is carried out by using the SFP module of Agilent N5980 error detector. The tested equipment is placed in the high and low temperature chambers, and the test temperature is -43℃, 20℃ and 60℃ respectively. The test rate is 3.125 Gb/s, code type is PRBS 2^15-1, the test time is 2 minutes.

![System Error Test Connection Diagram](image)

Table 4. Error Test Results

| Nominal central wavelength (nm) | -43℃ | 60℃ | 20℃ |
|---------------------------------|------|-----|-----|
| 1310                            | 0    | 0   | 0   |
| 1330                            | 0    | 0   | 0   |
| 1470                            | 5.329 E-012 | 0 | 0   |
| 1490                            | 2.887 E-007 | 1.897 E-006 | 4.313 E-006 |
| 1510                            | 0    | 0   | 0   |
| 1530                            | 0    | 0   | 0   |
| 1550                            | 0    | 0   | 0   |
| 1570                            | 0    | 0   | 0   |
The experimental results show that the system bit error rate of 1490nm channel is 10^-7~10^-6, which has exceeded the design target range of bit error rate of optical fiber communication system, resulting in errors in data transmission of this channel and affecting the application of links.

3.5. System Eye Diagram Template Testing (System Jitter Test)

In order to analyze the cause of the error, the sampling oscilloscope is used to analyze the eye diagram of optical communication when there is a large error. In this experiment, the bit error rate (BER) of the 3.4-section BER test is compared and analyzed between the wavelength 1490 nm channel and the 1330 nm channel of the previous experiment.

Fig.6 is an optical eye diagram of the 1490nm channel and 1330nm channel at -43℃. The test equipment is Keysight 86100D sampling oscilloscope (oscilloscope module 86105C, clock recovery module 83496B), the optical signal rate is 3.125 Gb/s, and the data source is Agilent N5980A error detector.

![Systematic Transmission Eye Diagram](image)

Figure 6. Systematic Transmission Eye Diagram

The jitter time of 1490 nm channel was 27.5 ps, and that of 1330 nm channel was 7.0 ps. Through eye diagram analysis, the jitter of the rising edge of the optical signal is obvious, which will affect the bit error rate of the optical signal.
Template testing of the above signals shows that the 1490nm channel optical signal has not passed the template test, while the 1330nm channel optical signal has passed the template test. The experimental results show that the optical signal of the 1490 nm channel does not meet the requirements of the application template specification and cannot guarantee the reliable transmission of data in this channel. In the follow-up test, the eye diagram of the output optical signal of the transmitter wavelength converter was tested, and it was found that the output eye diagram of the channel wavelength converter failed to pass the corresponding template test, locating the fault in the transmitter wavelength converter module.

4. Conclusion
Through the test, the performance and working state of the optical fiber transmission WDM system and the performance index of each device in the system can be analyzed in depth. It can provide a basis for optimizing system design, evaluating system reliability margin and analyzing system fault.

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