Design Method of Long Distance Optical Transmission Equipment for S Band RF TT&C Signal

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Abstract

S band is one of the main working frequency band used by aerospace TT&C (Tracking, Telemetry and Control) system. With TT&C network an increasing scale, the new demands on overall arrangement of TT&C ground station and surroundings of staff are generated. Therefore, the traditional RF signal transmission method has been not suitable. The RF TT&C signal transmitting method use of fiber instead of cable is proposed in this paper. With S band TT&C ground station as a platform, the model of optical transmission signal is established, and the optical transmission equipment is designed. Finally, the testing environment based on TT&C ground station is established, and the performance specifications of optical transmission equipment are tested. Testing results show: the RF TT&C signal can be transmitted 56km long by optical equipment in normal operation condition. The problem of RF TT&C signal long distance transmitting for large scale TT&C ground station is resolved effectively.

1. Introduction

S band TT&C system is one of the main equipment used to support aerospace onboard management. Its main task includes: ① To amplify, down-convert and demodulate the S band signal received from an aerospace. The measurement information is obtained to determine the aerospace orbit. The telemetry information is obtained to monitor the aerospace working status. ② To code, modulate, up-convert and amplify the telecommand and inject data, and send them to the aerospace to realize control and operation. Traditionally, low noise amplifier, high power amplifier and antenna control unit are located inside the antenna mounting, and down/up converter, antenna coded unit and base band processing unit are assembled inside the control room. RF signal is transmitted with cable from antenna mounting to control room. The distance between two sites is about 100m[1-2].

With the development of aerospace field, massing of TT&C equipment is increasing, and the level of automatic operation is improving. The problem of electromagnetic interference and shelter between antennae should be considered because of a large number TT&C equipments assembled in same station. In addition, the safety problem of operator should be considered also, with the increase of antenna aperture and transmitting power. In view of the above reason, the TT&C antenna is required far from the control room, and the appropriate distance is far than 50km.

NASA and other related institutions have carried out the research of optical transmission, for the long distance TT&C RF signal transmitting problem. The optical fiber is used as a media to transmit video signal by America Electro-Magnetic Processes Inc. Its transmission distance is 25km, and the function of remote operation for telemetry receiving equipment is therefore realized [3]. Another optical transmission system for X band deep space TT&C signal is designed by NASA JPL (Jet Propulsion Laboratory). Its transmission test of 12km is successful [4-5]. At the same time, the research and test also have been carried on by the experts for transmitting time and frequency signal in TT&C network. For example, the optical is used to transmit time and frequency signal of array antenna in NASA deep space network [6]. The related research in this field has been carried on by Chinese experts also [7].

In this paper, the S band signal optical transmission system is researched and designed with the goal of 50km transmitting distance. The model of optical signal transmission is established in the second section of the paper. In the third section of the paper, the optical transmission equipment is designed. Finally, the test platform is established, and the test results are analyzed.

2. Integrated photovoltaic Signal Transmission model

Figure1 shows the integrated photovoltaic TT&C signal transmission system based on TT&C station.

There are two key problems to design the optical transmission equipment of RF TT&C signal, one is to guarantee the consistency between sum and difference channel, another is to satisfy the need of high receiving sensitive. Therefore, the designed method of downlink optical transmission equipment will be discussed here. Assume the downlink signal from a satellite can be expressed as

$$s(t) = A\cos[\omega_c t + bc(t) + \sum_{i=1}^{K} m_i \sin\Omega_i t] \tag{1}$$

Here, A is carrier magnitude; ω_c is carrier angle frequency; b is carrier modulation index which is modulated by ranging code; c(t) is code waveform; m_i is carrier phase modulation index which is modulated by the ith sub-carrier; Ω_i is angle frequency of the ith sine sub-carrier.

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The signal in antenna input port can be expressed as

$$S_a(t) = A/L_{sp} \cos[\omega_c t + bc(t) + \sum_{i=1}^{K} m_i \sin \Omega_i t] + N(t) \quad (2)$$

The optical transmission model of signal in formula (2) can be expressed as [8-9]

$$S_{optical}(z,t) = A/(L_{sp} * L_{optical}) \cos[2\pi(zf/c - ft) + bc(t) + \sum_{i=1}^{K} m_i \sin \Omega_i t] + N(t) \quad (3)$$

Here, assume an optical plane wave propagating in free space in the z-direction.

In TT&C system, the measurement accuracy and satellite telemetry bit error rate will be affected by signal noise feature.

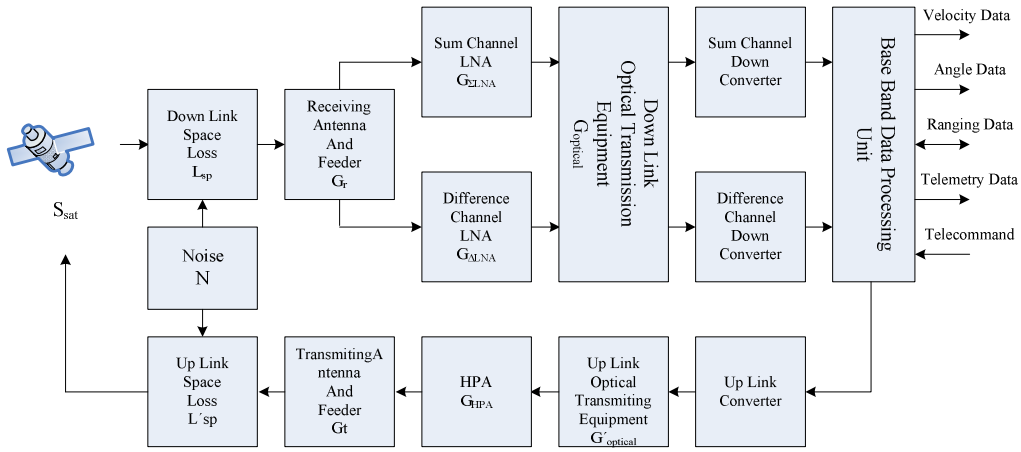

Figure 1 Diagram of integrated photovoltaic TT&C signal transmission system

3. Design Method of Integrated photovoltaic Signal Transmission Equipment

3.1 Design Method of Consistency of Sum and Difference Channel

Four wavelength division multiplexing (WDM) system is used to realize two channel RF signal coupling transmission with one fiber. At the same time, the wavelength of multiplexer and demultiplexer are choosen reasonably in wavelength division multiplexer, in order to guarantee the consistency of insert loss of four channel optical signal. Thereby, the demand of consistency of sum and difference channel can be satisfied.

The optical wavelength division multiplexer is a kind of optical passive device. It uses optical filter to compose and split the optical beam. The main specification of an optical wavelength division multiplexer is insert loss. Generally, the central wave length is same for the optical wavelength division multiplexer and optical wavelength division de-multiplexer. But when it is applied in an engineering system, the insert loss is different for each channel. It is almost 2dB loss for four beam of optical wavelength division multiplexer. The optical wavelength division multiplexer in our system is customized, and its insert loss is small.

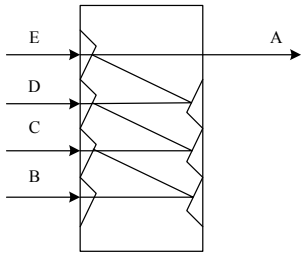

Figure 2 Schematic diagram of WDM

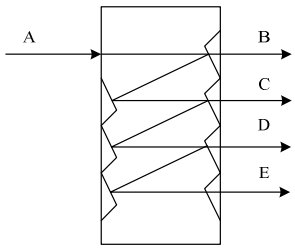

Figure 3 Schematic diagram of WDDM

Figure 2 shows the schematic diagram of four channels optical wavelength division multiplexer. Here, “A”is the wavelength combined with λ1, λ2, λ3and λ4; “B” is the wavelength of λ1; “C” is the wavelength of λ2; “D” is the wavelength of λ3; “E” is the wavelength of λ4.

In Figure 2, λ4 is chosen as central wavelength. In channel four, λ4 is output through one time transmission, and its insert loss is about 0.5dB. In channel three, λ3 is output through one time transmission and two times reflection, and its insert loss is about 1.0dB. In channel two, λ2 is output through one time transmission and four times reflection, and its insert loss is about 1.5dB. In channel one, λ1 is output through one time transmission and six times reflection, and its insert loss is about 2.0dB.

In Figure 3, λ1 is chosen as central wavelength. In channel one, λ1 is output through one time transmission, and its insert loss is about 0.5dB. In channel two, λ2 is output through one time transmission and two times reflection, and its insert loss is about 1.0dB. In channel three, λ3 is output through one time transmission and four times reflection, and its insert loss is about 1.5dB. In channel four, λ4 is output through one time transmission and six times reflection, and its insert loss is about 2.0dB.

Here, λ1, λ2, λ3and λ4 are designed according to ITU-T standard. The standard wavelength is 1550.12nm and wavelength interval is 4×0.8nm: i.e. λ1=1550.12nm, λ2=1553.32nm, ， λ3=1556.52nm and λ4=1559.72nm. In the system, λ1 is selected as sum signal and λ4 is selected as difference signal. The insert loss is same for each wavelength because of being used in proper proportions, i.e. λ1 (1550.12) = 0.5(demultiplexer)+2.0(multiplexer)= 2.5dB，λ2 (1553.32) = 1.0(demultiplexer)+1.5 (multiplexer) = 2.5dB，λ3 (1556.52) = 1.5(demultiplexer)+1.0 (multiplexer) = 2.5dB，λ4 (1559.72)= 2.0(demultiplexer)+0.5 (multiplexer) = 2.5dB.

Therefore, the insert loss of each channel is 2.5dB through four wavelength division multiplexing system, and it smaller than maximum insert loss specification of 4dB.

3.2 Design Method of Extend Dynamic Receiving Range

Currently, EDFA (Erbium-Dropped Fibre Amplifier) is used in the DWDM (Dense Wavelength Division Multiplexer) optical transmission system widely. But, its noise figure is bigger than what is demanded by the deep space TT&C system. When the signal is transmitted through a long distance, the optical signal to noise ratio will be degraded for the reason of accumulated noise. Also, the signal to noise ratio for electricity signal will be degraded. At the same time, the nonlinear problem of long distance fibre transmission will be caused [10].

In order to overcome the accumulated noise, the FRA is chosen for optical transmission system. The FRA can be used to realize long wavelength amplify. Figure 4 shows the basic structure of distributed FRA.

Here, the FRA gain is related with the length of optical fibre cable. And, the gain wavelength is determined by optical pump. Any wavelength signal can be amplified by it, theoretically. Technically, the FRA is a kind of distributed amplifier. Its gain medium is transmission optical fibre. The amplified function is uniformity distributed along the optical fibre cable. The signal optical power averaged in the transmission optical fibre is weak enough to meet the system demand. And, the nonlinear problem of long distance fibre transmission will be overcome.

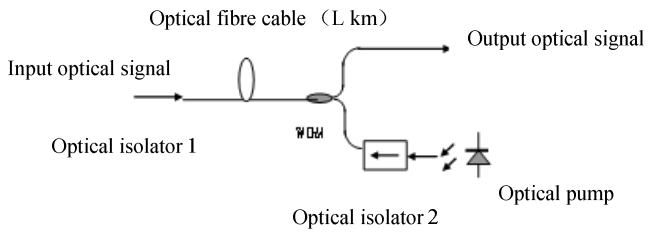

Figure4 Basic structure of distributed FRA

Due to FRA gets amplified gain by the method of distributed amplify, its noise figure is about 0～1 dB. The optical signal to noise ratio is improved so that the transmitting distance is increased.

4. Analysis of Test Result

The performance of optical fibre transmission system is tested according to Figure 5.

The static performance of optical fibre transmission system is tested according to figure 6, and the test result is showed in Table 1. The dynamic performance of optical fibre transmission system is tested according to figure 6, and the test result is showed in Table 2.

Table 1 Test results of static performance

Name of index	Specification	Index test results
Transmission distance	≥40km	56km
Extend Dynamic Receiving Range	－120dBm～－10dBm	-119dBm～-10.62 dBm
Link gain flatness	0.35dB/25MHz	0.34dB/25MHz
	±0. 3dB/300MHz	±0.26dB/300MHz
Amplitude stability	0.5dB/24h	0.43dB/24h
Signal isolation	60dB	70dB
Group delay stability	0.5ns/12h	0.12ns/12h
Gain stability	0.25dB/24h	0.25dB/24h
Number of transmission channel	≥4 路	4 路

Table 2 Test results of dynamic performance

Name of index	Index test results（20m cable）	Index test results（56km fiber）
Range measurement random error	10.09 m	10.12 m
Velocity measurement random error	0.265 cm/s	0.28 cm/s
Telemetry BER	$\leq 1.0\times10^{-5}$	1.93×10^{-6}

Comman error rate	≤ 1.0×10^{-6}		0	
Tracking performance	A=495mv/mil	E=494mv/mil	A=510mv/mil	E=511mv/mil
Receiving noise figure	0.691 dB		1.11dB	
Group delay stability	≤ 3 ns/24h		2.8 ns/24h	

The test results show that the system specification has been satisfied after transmitting signal with 56km long fiber. The TT&C accuracy is not change compared with original system.

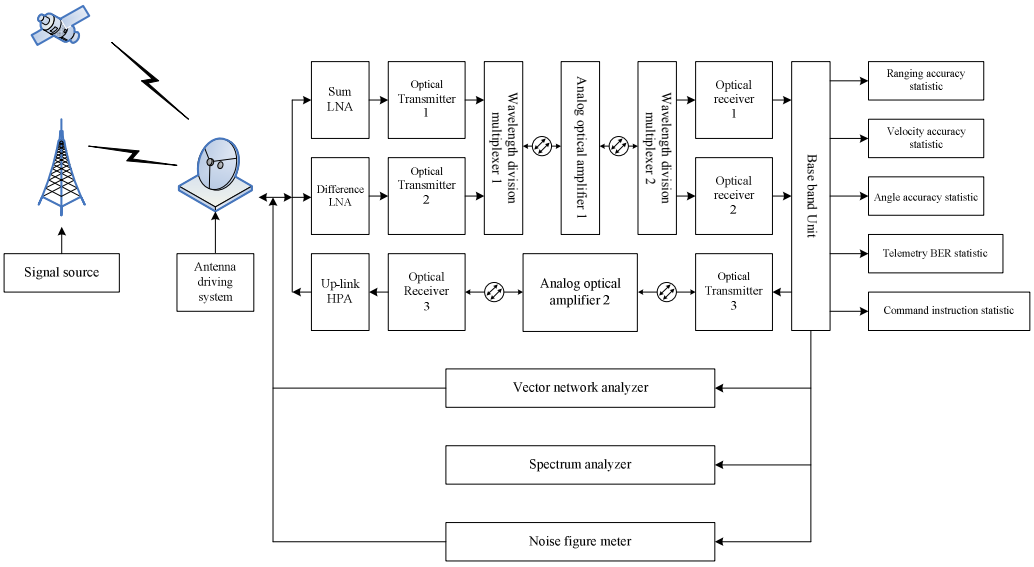

Figure 5 System test layout

5. Conclusion

In this paper, the integrated photovoltaic RF TT&C signal transmission equipment is designed for the purpose of RF signal long distance transmission. The insert loss of four channels is basically the same by means of designing four WDM. The problem of long distance transmission for RF TT&C signal is resolved by means of designing FRA. The transmission distance can reach to 56km.

The test results show: the static performance and dynamic performance of optical fibre transmission system are met the specifications of original system. The integrated photovoltaic RF TT&C signal transmission equipment is being applied to Chinese mainland TT&C ground station.

6. Acknowledgments

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