Research on space coherent laser communications technology

Song Lu[a], Song Tong[b], Zhu Yi feng[a], Liu Quan[a], DuanMu Fan Yi[c] ,Yu Lin Tao[a]
[a]Changchun University of Science and Technology; [b]Dalian University of Technology; [c]Beijing Instieute of Technology

ABSTRACT

In this paper, we research the laser transmission characteristics in the space channel environment and on which basis, research the overall composition of coherent space laser communication systems and focus on its key technologies, including high-speed outer optical modulation technology, optical phase locking technology, photo mixing technology, optical heterodyne detection and optical signal processing technology, Finally, the article looks for prospects on the development of coherent space laser communication .

Key Words: Laser Communication, Coherent Detection, Space Channel

1. INTRODUCTION

The space laser communication refers to the laser beam in space as a carrier for a data communication. It has become an important research direction in the field of space communications as a result of its characteristics, which include the narrow emission beam,large information capacity,strong confidentiality and low power dissipation.

The communication mode of space laser communication is divided into two types: one is the laser intensity modulation / direct detection (IM / DD) mode, and the other is a multi-mode modulation / coherent laser reception. At present, the IM / DD mode is the main mode of the space laser communication method.

But for the space laser communication systems, it has raised higher demands upon information capacity,communication speed,transmission distance and equipment miniaturization. So the IM / DD mode can not fully meet the actual demand because of its modulation and detection methods' limitations.

As the development of the space laser communication technology, Coherent Laser Communications is great potential communications system, Comparing to the IM / DD mode, it has a higher detection sensitivity, a smaller diameter antenna to send and receive,miniaturization,low power dissipation, the more Stronger anti-capacity for background light,more flexible modulation, as well as a higher rate of transmission.

Coherent Laser receiver system has become the important means of technology to develop a new generation of high bit-rate, miniaturization and low power dissipation space laser communications terminal

2. THE BASIC COMPONENTS OF SPACE COHERENT OPTICAL COMMUNICATION SYSTEMS

The basic block diagram of Space coherent optical communication system as shown in Fig.1

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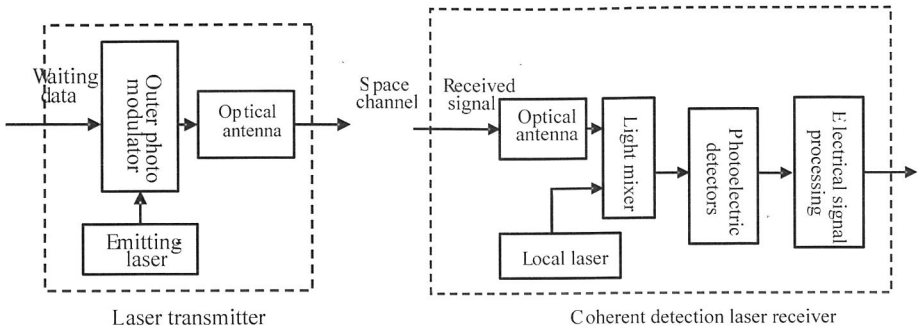

Fig.1 The basic block diagram of Space coherent optical communication system

Space laser communication system is composed of the optical antenna,Lasing source,optical modulator,light mixer,local oscillation source,photoelectric detectors,signal processing circuit.

At sending end, the data to be transmitted was sent out through the channel space after the modulation of laser, when the optical transmission signal reached the receiving end, First of all, it would have the coherent mixing with an optical vibration signal and then was received by the photoelectric detector, signal processing ,to restore the original signal. Assuming the responsively of Photoelectric detector is S, then through a mixer, the photocurrent contained information can be expressed as:

$$i_s(t) = aS\sqrt{P_s P_l}\cos(\omega_{1F}t + \varphi_s - \varphi_l) \qquad (1)$$

Where P_S, P_l and φ_s, φ_l respectively represent for the power and phase of the signal light and LO light, ω_{IF} is frequency difference of the signal light with LO light, the ω_{IF} is given by: $\omega_{1F} = \omega_S - \omega_l$,for $\omega_{IF} = 0$, $i_s(t)$ expresses **h**omodyne detection, for $\omega_{IF} \neq 0$,it expresses optical heterodyne detection.

3. THE EFFECTS ANALYSIS OF THE SPACE CHANNEL ENVIRONMENT ON COHERENT SPACE LASER COMMUNICATION SYSTEMS.

For terrestrial and space laser communications, laser though the atmosphere channel will have decay and the effects of atmospheric turbulence. As random fluctuations in the atmospheres refractive index, resulting in the intensity and phase of waves are a phenomenon of random fluctuations in time and space. Which impact probability and intensity are random.

We used Rytov variable to measure the effects of atmospheric turbulence on light transmission. It is given by:

$$\sigma_t^2 = 1.23 C_n^2 k^{7/6} L^{11/6} \qquad (2)$$

Where C_n^2 is the refractive index structure parameter; k denotes the wave number($2\pi/\lambda$);L is the transmission distance of wave. When $\sigma_t^2 < 1$,it is weak turbulence, when $\sigma_t^2 \approx 1$,it is moderate intensity turbulence and when

σ_t^2 >>1,it is strong turbulence. Optical turbulence swirl is winth the range l_0 to L_0. l_0 is the inner scale of turbulence swirl and L_0 is the outer scale of turbulence swirl.

Light intensity scintillation effect caused by Atmospheric turbulence subject to lognormal distribution. Which is given by:

$$P(I)=\frac{1}{2\sqrt{2\pi}\sigma_x I}\exp\left\{-\frac{\left[In(I/I_0)+2\sigma_x^2\right]^2}{8\sigma_x^2}\right\} \quad (3)$$

Where I_0 denotes the mean of light intensity, σ_x denotes scintill logarithmic amplitude).ation index(The standard deviation of optical signal

In Fig.2,The curve of average laser spot brightness detected by CCD at 3km transmission distances.

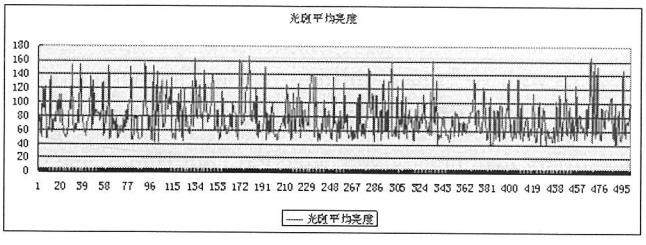

Fig.2 The curve of average laser spot brightness detected by CCD at 3km transmission distances

The atmospheric turbulence result in surface-wave vibrating, spot split,the wave of received angle, Which bring about prominent effects on mixing efficiency of coherent communication, at the same time, the background light interference make the sensitivity of coherent detection lower and signal to noise ratio decrease.

4. THE KEY TECHNOLOGIES OF COHERENT SPACE LASER COMMUNICATION

4.1 The narrow linewidth and high frequency stabilization technology about laser light source.

High frequency stability and narrow linewidth laser is a key technology in coherent space laser communications system design. For PSK heterodyne systems,the requirement is the order of magnitude of the product for the laser line width and bits cycle to 10-4.As for homodyne systems, because of a higher detection sensitivity, the laser line width of the maximum allowable requirements more stringent. Which require the frequency stability of laser light source is more than 10E-5 of carrier frequency.

At present, with the integration of electronic devices improved, laser technology has got significant progress, the types of lasers include miniature external cavity semiconductor lasers,integrated external semiconductor lasers as well as DFB,DBR new structural lasers.

In system design, there will be automatic laser frequency stability control unit, which is used to inhibit frequency drift phenomenon caused by the temperature change of laser components.

4.2 High-speed outer laser modulation emission technology

In coherent laser communication systems, there are many kinds of laser modulation modes including ASK / PSK / DPSK / FSK mode.generally,we adopt outer modulation technique. for Gbps communication systems, It is essential to research the high-speed , high-power laser modulation systems.

4.3 Coherent Light mixing matching technology

Optical coherence detection technology is the the core of Coherent Laser communication technology, and its quality was impacted by optical coherence mixing efficiency.the mixer realizes the coherent light signal mixing function of receivd light with LO light on receiving. Especially heterodyne detection,which has coherent operations based on two different frequencies, the same polarization beam in the space.In order to obtain high efficiency of the heterodyne, It is essential to ensure that the signal light with LO beam were parallel sent and vertically reach the detection. but also to ensure that geometric center of the two light beam spots are coincidence, the spots overlap. At the same time, also called for the same polarization for the two light beams .

Due to the impact of turbulence, when optical communication transmission through the atmosphere,the wavefront will have a random distortion and polarization surface will occur erratical changes ,which makes the mixing efficiency of communication laser with the vibration light is very low. Therefore, we need to develop the wavefront correction of Coherent light and Polarization adaptive systems and have the research in optical mixer structure of input and output . At present, there has be the optical mixer devices with 90 ° phase-shifting , four-channel mixer output structure .

4.4The optical phase locking technology of Homodyne detection receiver

Homodyne detection has more higher sensitivity than heterodyne detection , but Homodyne system requires the receiver wave with local laser wave are on all fours in the frequency and phase. As a result, it needs a feedback control system to make the vibration frequency of the laser can automatically track frequency changes received signal light ,achieving automatic tracking for the frequency and phase between local oscillation light and signal light. So we need for high-precision phase locked loop (OPLL) circuit, including a balanced phase-locked loop, phase locked loop-driven decision-making and Costas phase-locked loop technology and so on.

The linear model of optical phase-locked loop as shown Fig.3

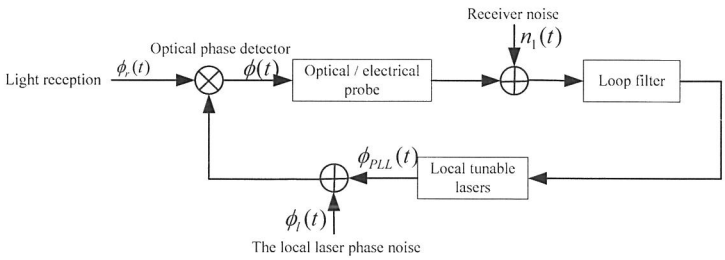

Fig.3 Optical phase-locked loop handling model

Optical phase-locked loop and the small power phase-locked loop with the two key part of the mixer is light instead of electric mixer, using the external-cavity tunable lasers instead of a voltage-controlled oscillators.

4.5 High-speed signal detection and processing technology

The form of detection of coherent communication system is divided into homodyne detection and heterodyne detection. From the sensitivity and reliability requirements of long-distance communication link, the PSK homodyne system with the maximum sensitivity is more suitable for long-distance high bit-rate coherent space communications. For homodyne detection system, the optical signal by the photoelectric conversion was directly converted to baseband signals. For

heterodyne detection systems, optical signal by the photoelectric conversion coming into the intermediate frequency signal, the second modem can be converted into a base-band signal. In heterodyne detection system, receiver will adopt the automatic frequency tracking (AFC) technology of vibration frequency W_l to signal laser frequency W_s to control the effect of the channel environmental and the frequency drift of W_{IF} produced by the temperature changes of laser components.

5. THE PROSPECT OF SPATIAL COHERENT OPTICAL COMMUNICATION

Spatial coherent optical communication, as a new means of space communication that a high sensitivity, high anti-ray background interference, multi-mode of modulation, Has become to the best option to solve the bottleneck of space laser communications of high-speed, high-capacity, long-range, small-scale technology. spatial coherent optical communication in the field of optical communication in the future is an important direction of development. The key technology of spatial coherent optical communication has been resolved, which will lay the foundation for effective technology on the practical application of coherent optical communication.

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