Research on Inter-Satellite Laser Terminals Applied in Free Space

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Abstract

It is generally recognized that laser link is an effective means to achieve inter-satellite communication. In this paper, basic composition of inter-satellite laser link is firstly introduced. And then, operating factors include link budget, communicational parameter, capture strategy, servo control and etc. are designed. Finally, key technologies such as acquisition, tracking, and detection are analyzed.

Keywords

Laser Link, Free Space, Signal Acquisition.

1. Introduction

With the increasing demands of high resolution in time and space, to build space-based information network is extremely urgent. Therefore, inter-satellite transmission means with large bandwidth, high transmission speed, anti-interference, and high security should be developed. Undoubtedly, laser link is the best way to improve communication efficiency [1-2].

Compared with the traditional microwave links, laser link has these following significant advantages.

(a). The bandwidth increases significantly, which will provide greater communication capacity.

(b). Under the same requirements, laser link antenna will have small size and weight. It will reduce the pressure of platform.

(c). Laser will point to the small area, which will increase power density. The divergence angle will reduce with 3-5 orders of magnitude, which will improve communication secrecy;

(d). The free space is an excellent medium for light. Therefore, the laser is the ideal technology to achieve inter-satellite communications, thus expanding the network applications [3-4].

2. Basic Compositions

The basic composition of laser communication link includes: laser signal transmitter, signal transmission path and laser signal receiver [5].

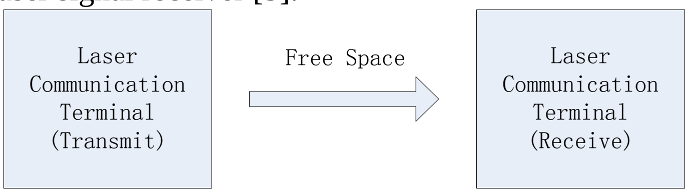

Fig. 1 the basic composition of laser link

Core functional parts of inter-satellite laser communication terminal include light machine unit, servo unit and communication unit.

Machine unit will be integrated in a compact, precise and efficient optical base station. Machine unit includes telescopic, spectral optical components and precision mechanical components.

Servo unit will realize accurate pointing, rapid capture and precision tracking, which will be the premise and guarantee of long-range laser communication between moving platforms. Servo system is made up of capture servo sub-unit and tracking servo sub-unit. With different combinations, servo unit will complete capture and tracking process.

The core function of communication unit is to realize the high efficiency, high power transmission and high detection sensitivity. According to the requirements of different tasks, laser power and system detection methods will be designed.

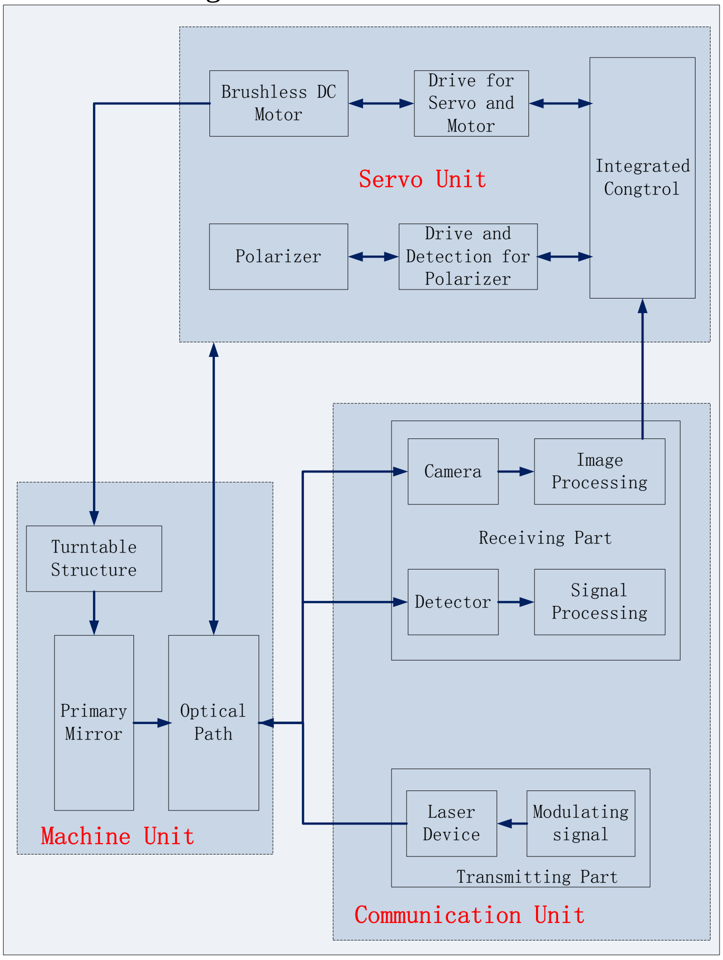

Fig. 2 Composition of space-borne laser communication link terminal

3. Operating design

3.1 Link budget design

Link budget design is the key process, where the receiving signal power, background noise, and sensitivity should be fully evaluated. Here, the wavelength, link distance, launching power, aperture area, launching optical efficiency, receiving aperture area, aiming loss and etc. will affect the receiving signal power. Aperture area, receiving efficiency of optical system, detecting view, receiving optical bandwidth, background radiation, the dark currents of probes and etc. will affect the receiving noise power. Detector quantum efficiency, noise character, signal modulation, coding schemes and etc. will affect the sensitivity of the receiver.

3.2 Communication system design

For the scenario requiring high speed in space communication, homodyne or heterodyne coherent system will be selected regularly, which has the characteristics of high speed and high sensitivity. However, coherent receivers will be complex, where the power cost and quality will increase. This will not be the economic to apply coherent receivers in slow speed communication scenario. Therefore, to choose the detectors such as APD or four quadrants QD will be suitable.

3.3 Communication wavelength design

Currently, available laser communication bands include 800nm, 1060nm and 1550nm. Each band has its advantages and disadvantages for the laser communication link. In contrast, 800nm is mainly applied to the condition of beacon light or low speed scene. From the perspective of technology and engineering, the 1060nm and 1550nm bands are ideal communication bands of laser communication. Among them, 1550nm has been widely used in optical fiber communication, and its technical maturity is better than 1060nm. However, with the continuous development of laser technology in 1060nm band, the optical power will be getting higher and higher, and the anti radiation ability will be more and more strong. 1060nm band will also become an optional band for inter satellite laser links.

3.4 Capture strategy design

In the same sequence, optical transceiver A starts scanning in uncertainty region. If laser signal of optical transmitter A received by optical transceiver B, optical transceiver B will calculate the position of optical transceiver A in this time according to the triggering time and camera target trajectory.

According to this position, optical transceiver B will adjustment pointing, and alignment to optical transceiver A roughly until a new smaller capture uncertainty area is formed. Then, the optical transceiver B scans in a smaller uncertainty area. The two sides scan and adjust alternately, and ultimately to achieve the capture. The accuracy and stability of the time system is very important in the whole process of capture, so high precision clock reference is needed.

3.5 Aiming method design

Considering the long distance communication of free space, the laser beam divergence angle is small. Variable window camera is generally used as feedback unit of tracking and pointing system. Servo is used as a coarse tracking mechanism. Vibrating mirror is a second servo mechanism for fine tracking. Composition of coarse tracking and fine tracking, the stability of tracking will be ensured.

3.6 Optical structure design

At present, there are two forms of optical antenna structure, which are card-mode system and the transmission-mode system. The advantage of card-mode system is simple in structure designing. But its disadvantage is that the energy utilization rate is lower. There is no central obscuration in transmission-mode system. In contrast, quality and price are more reasonable.

3.7 Servo structure design

The structure of servo control are numerous, such as scanning mirror, theodolite structure, circumferential scan scheme, L type single arm structure. Specific selection should be selected according to the actual coverage and the size of machine structure.

4. Key technologies analysis

4.1 Rapid acquisition technique for narrow divergence angle beam

The beam divergence angle of inter-satellite link is several tens of rad, and how to quickly capture the light signal in the narrow beam divergence angle is crucial. From the angle of lightweight design and low power consumption, no beacon acquisition technology is the first choice. How to realize fast acquisition by micro arc beam in the uncertain region of the arc is difficult. The key process is to establish a mechanism to reduce the size of the uncertainty region. The main factors affecting the performance of the capture unit include: capture strategy selection, boresight pointing accuracy, uncertain initial scanning area, scanning mode, field of view, device bandwidth and etc. (Figure 3).

4.2 High precision and high dynamic signal tracking

Under dynamic conditions, in order to ensure the measure precision and communication rate of laser link, the alignment accuracy of the Los 1/8 to 1/6 divergence angle of beam should be established. Therefore, tracking accuracy with micro arc is important. The main error sources that affect the precision of tracking are spot detection error, dynamic lag error, platform vibration residual error, and etc.. The detector bandwidth, detection accuracy and sensitivity are the main factors that restrict the improvement of the spot accuracy. The traditional QD spot position detection is based on the principle of energy detection. In the optical heterodyne interference, due to the strong energy of the vibration, the change of the spot position caused by the incident light energy change is not obvious, which cannot meet the requirements of the detection accuracy. Poor spot position based on wavefront sensing technology is achieved by detecting the phase difference between the incident light and the vibration wave. To study the relationship between the optical heterodyne efficiency and the spot position include the influence of pattern matching, alignment deviation, spot size matching, polarization matching and so on. In addition, the bandwidth of the control unit, the resonant frequency of servo system and intelligent control compensation algorithm should be improved to ensure the accuracy of micro arc tracking.

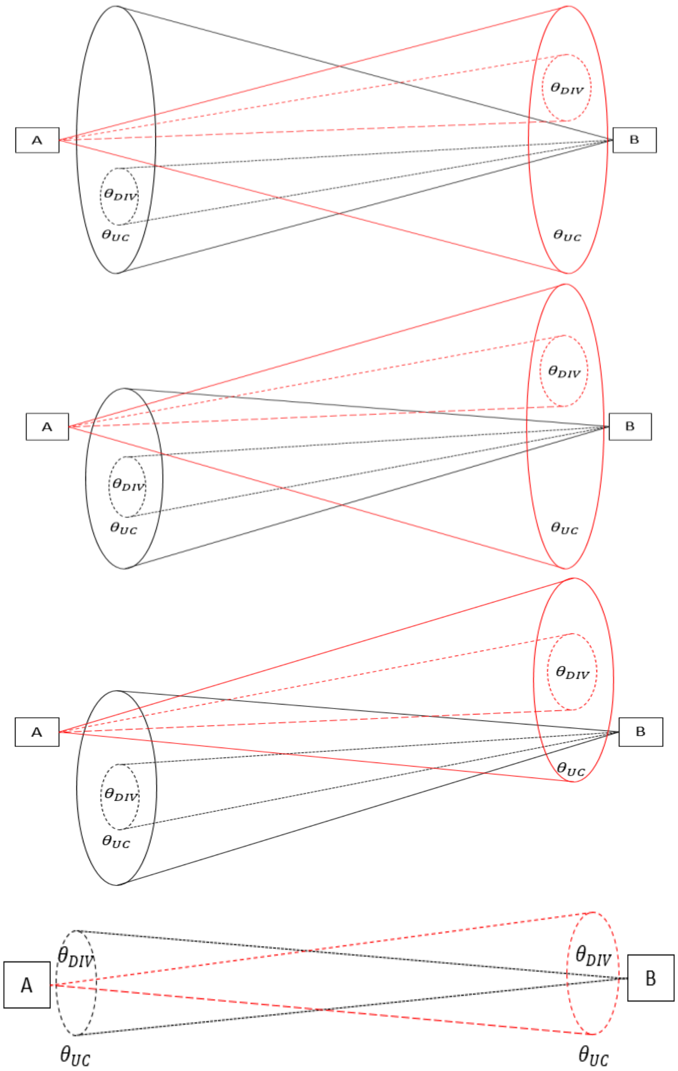

Fig.3 Capture process of inter-satellite laser link

4.3 High sensitivity signal detection and demodulation technology

In order to realize communication in long distance ranging under the condition of limited optical aperture, to improve the sensitivity of the detector is the key technology. One of the important difficulties in the communication signals demodulation is the line width and frequency stability of the signal source, where the index demand is very strict. For heterodyne coherent demodulation, acquisition and tracking IF signal is also involved. There are three components of signal after tracking, which should be compensated correspondingly. Firstly, the center frequency of the signal should be compensated. Secondly, the Doppler shift caused by the relative motion should be compensated. Thirdly, the frequency stability should be compensated. The frequency stability is a random parameter， which will directly affect the bandwidth of the PLL loop, and then affect the stability and performance of the coherent demodulation.

5. Conclusion

Laser communication will improve the efficiency of satellite network, which will provide a new development opportunity for the application of space network. Meanwhile, according to the current market demand of the laser link terminals, laser link will develop with following directions.

(a). Spectrums development

Laser link terminals will be produced by spectrums according to different networking needs such as GEO-LEO link, LEO-LEO link, MEO-MEO link and others. The terminal products will be standardized.

(b). Platform adaptation

Working environment such as temperature is influencing factor for laser load components. So future laser link terminals should have the ability to control the temperature of the load itself, to reduce the dependence on the platform.

(c). Self calibration on orbit

The laser beam is narrow, so the installation process requires accurate ground calibration. However, the launch process and long time working on orbit will introduce some errors. Self errors calibration is needed.

(d). Cross layers fusion

The design of the laser link need to be integrated with physical layer, data link layer, transport layer, network layer and application layer, to maximize the effectiveness of the application.

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