

Current Status, Development Trend and Key Technology Analysis of Space Laser Communication

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Abstract: This paper starts from domestic and foreign current status of space laser communication, and analyzes the development trend and key technology of space laser communication.

1. Domestic and Foreign Current Status of Space Laser Communication

The domestic and foreign current status of space laser communication is analyzed in foreign airborne and ground laser communication, and foreign space laser communication.

1.1 Foreign airborne and ground laser communication

The technological achievements of foreign space laser communication are shown in Table 1.

Table 1 The technological achievements of foreign space laser communication

Link type	system	Carrying terminal	nation	time	speed
Satellite and ground	SLS	International Space Station and North Caucasus Ground Station	Russia	2012	125Mbit/s
	LLCD	Lunar environment detector and ground station	America	2013	收 622Mbit/s 发 20Mbit/s
	OPALS	International Space Station and Whitewood Ground Station	America	2014	50Mbit/s
Satellite and space	LOLA	Artemis Satellite and Mysterious 20 airplane	France	2006	50Mbit/s
satellites	LCTSX	TerraSAR-X Satellite and NFIRE Satellite	Germany and America	2008	5.65Gbit/s
	EDRS	Sentinel 1-Alphasat	Europe	2014	1.8Gbit/s
Space and space	Falcon	Airplane and airplane	America	2011	2.5Gbit/s
Ground and ground	—	La Palma Island and Tenerife Island	Germany	2005	5.6Gbit/s
Space and ground	—	Airship and ground vehicle terminal	America	2006	40Gbit/s
	ARGOS	DLR airplane and ground station	Germany	2008	150Mbit/s

1.2 Domestic space laser communication

Domestic space laser communication started very late, which is highly emphasized. The experimental link of domestic space laser communication is shown in Table 2.

Table 2 The experimental link of domestic space laser communication

Link type	Carrying terminal	Unit	Time	Communication speed	Distance
Ground and ground	Two ground terminals	CETC No. 34	2000	155Mbit/s	26km
	Ship- ground	Changchun University of Science and Technology	2007	300Mbit/s	20.4km
	Two ground terminals	Wuhan University	2010	7.5Gbit/s	40km
	Two ground terminals	CETC No. 34	2014	2.5Gbit/s	5km
Satellite and ground	Ocean 2 Satellite—ground station	Harbin Institute of Technology	2011	504Mbit/s	2000km
underwater	ship—under water	SIOM	2010	10Kbit/s	125m
Space and ground	airship—ship	Changchun University of Science and Technology	2011	1.5Gbit/s	20.8km
Space and space	Two helicopters	Changchun University of Science and Technology	2011	1.5Gbit/s	17.5km
	Two-transportation 12 airplane	Changchun University of Science and Technology	2013	2.5Gbit/s	144km

2. Development Trend of Space Laser Communication

At present, development trend of space laser communication is indicated in high speed, network, multi-purpose, integration and multi-spectrum.

2.1 High speed

Space laser communication is developing at a very fast pace. Specifically, first, as early as 2012, ESA proposed a satellite system. The satellites carried by the two payloads can reach a communication rate of 1.8 Gbit/s at a distance of 40,000 km. Second, in 2014, Japan's Yuhang Discovery Bureau plans to launch a transit satellite in 2019, with an expected communication rate of 1.8 Gbit/s; Third, in 2013, the United States proposed LCRD, and the satellite will be launched in 2016 with a communication rate of 2.8 Gbit/s; Fourth, the US laser communication company set up an ultra-high-speed laser communication network within four years. The network has 8 satellites and 48 ground stations, and the total communication rate can reach 200 Gbit/s

One of the advantages of high-speed spatial laser communication is that it can realize large-capacity real-time information transmission. The main difficulty lies in the difficulty in realizing the realization of high-power light source output and communication low bit rate. Therefore, the difficulties can be solved by combining the photovoltaic technology.

2.2 Network

At present, space laser communication is one-to-one, which directly affects communication relay, networking and its applications. It can be said that network is the most important development trend of space laser communication. First, as early as 2012, Japan proposed a two-layer low-orbit low-altitude satellite system networking plan; second, in 2003, the United States proposed the TSAT program, and many of the laser communication technologies in the program are still in the process of development. The networking mainly includes space-based laser communication network, air-based laser communication network, space-to-ground laser access network, and ground-to-sea laser emergency network.

The main advantage of laser communication networking is the ability to realize the fast, real-time and secure communication network. However, the technical difficulties are problems such as dynamic topology access and network openness. The main solution is to adopt dynamic routing to solve the access problem and improve the integrated communication protocol.

2.3 Multi-purpose

Space laser communication is widely used in communication links such as inter-satellite, satellite and space, space and space, space and ground, and is gradually expanding to deep space and submarine communications. First, as early as 2009, NASA proposed the MLCD program to develop deep-space high-data remote communication with a communication rate of 100 Gbit/s. Second, in 2005, a US technology company launched a potential data exchange and enhancement program.

It can be said that submarine laser communication is an important development field for laser communication, especially in military applications. In general, compared to traditional space laser communication, the advantage of submarine laser communication is that the low frequency rate is high, but the difficulty lies in the need to cross the atmosphere and seawater, and the laser scattering in seawater is very serious. The main solution is to use blue-green laser with better penetrability.

2.4 Integration

Space laser communication integration mainly refers to the combination of space laser communication and laser ranging and optical imaging to achieve integration. First, in the US X2000 project, the flight terminal uses shared signal lights with ranging and communication, scientific imaging and laser altimeters. In the second year, in 2005, NASA used the SLR2000 laser range finder as the beacon light for laser communication. Third, in 2013, NASA's LLCD system in the United States, in addition to the laser communication function, was able to measure the ranging flight time to the centimeter.

In the application of integration and development trend of measurement and communication, its main advantage lies in the realization of the combination of ranging and communication. The main difficulty lies in the poor anti-interference ability and weak ranging light energy. Therefore, the main solution is to use the method of ranging and communication common wavelength and modulation dual system.

2.5 Multi-spectrum

The multi-spectral laser communication mainly combines the development of multi-spectral directions such as ultraviolet light, visible light, infrared light and radio. The main purpose is to give play to the advantages of different spectrums in the communication system. First, in 2008, American companies realized real-time communication under outdoor sunlight. Second, Japan's Nagaoka University uses visible light communication technology.

3. Key Technologies of Space Laser Communication

3.1 High-quality optical system design technology

As one of the key technologies of space laser communication technology, high-quality optical system design technology mainly includes near-diffraction limit angle optical system design

technology, multi-optical axis consistency adjustment technology and high-precision capture alignment tracking technology.

For near-diffraction limit angle optical system design technology, the main difficulty is that the laser beam divergence is about 10,000 times compression, and the high-quality emission of the beam needs to be guaranteed. The technology can realize the emission near-diffraction limit, and the main optical structure is the structure of the phase structure of the large-diameter aspherical spectroscopic system. Then for multi-optical axis consistency adjustment technology, the technical difficulty lies in the high requirements for the consistency of multiple optical axes, mainly using CCD subdivision detection technology. Finally, for high-precision capture alignment tracking technology, the main difficulty lies in the need to assemble a variety of optical components, such as lasers, actuators, etc., and when using materials, lightweight and radiation-resistant materials shall be selected.

3.2 High-precision capture alignment tracking technology

The main workflow of high-precision capture alignment tracking technology is to determine the initial area of uncertain capture, capture coarse tracking, perform alignment fine tracking, and realize laser dynamic information communication. The most critical technology in the entire process is to capture coarse tracking and alignment fine tracking. The main difficulty of these two technologies is that the uncertainty area is large and the beam angle is small, so the capture time will be long and the probability will be relatively low. The main solution is to use precision attitude determination and pointing technology and speed vibration compensation technology. However, the main technical difficulty in aligning fine tracking is that the influence of platform vibration is large, then the application of intelligent digital control technology can be applied to improve system robustness.

3.3 Compensation technology influenced by atmospheric channel

When the laser beam propagates in the atmosphere, the atmospheric channel has a direct influence on the laser beam, mainly affecting the quality of the laser by attenuating the laser power, which will directly affect the spatial laser communication effect, and may even cause communication failure. In response to the problems, two measures can be taken. First, a wide-range laser light intensity stabilization technique is adopted, which is mainly realized by using an adaptive control algorithm. Then the high-precision real-time wavefront distortion correction technology is adopted, and the main way is to use the Hartmann sensor to achieve thin surface correction.

3.4 High-speed and high-power launch technology

High speed and high power are the most important technical requirements of the laser, which can not only effectively remove the background light, but also provide communication functions. The main application techniques of high speed and high power are internal modulation launch technology and external modulation launch technology.

For internal modulation launch technology, the difficulty is that the laser source must meet the requirements of high speed, high quality and high power. The technical approach is to develop high performance seed precursor lasers. For external modulation launch technology, the main difficulty is that the operating point of the bias voltage of the electro-optical modulation crystal is directly changed by the temperature change. The technical approach is to increase the peripheral temperature control feedback circuit, using multi-point side pumping to achieve high power output.

3.5 High-sensitivity and low-error detection technology

At present, intensity modulation direct detection technology and coherent detection technology are the two most commonly used detection techniques. For intensity modulation direct detection technology, the main difficulty is strong background interference, difficult signal extraction, and low receiving power. Therefore, the main technical approach is to use automatic gain extraction technology, and thermoelectric refrigeration technology and built-in preamplification technology. Then for coherent detection technology, the main difficulty lies in the narrow line width of light

source and the high efficiency of mixing. The technical approach is to develop a stable narrow linewidth laser to reduce the mismatch angle and improve the mixing efficiency.

3.6 One-point to multi-point communication technology

One-to-many communication technology is a necessary condition for the realization of space laser communication networking with the ability of middle and duplex communication. In general, the principle of one-to-many communication function can be mainly divided into the simple principle, exchange distribution, RF laser combination, and field of view expansion. The technical structure of different kinds of principles is also different. The technical difficulty of the rotating parabolic structure is that the communication range is wide and the utilization of light energy is low. The technical approach is to optimize the splicing structure of the multi-mirror to improve the utilization of light energy. For the three concentric spherical structure, the difficulty lies in the communication of the large field of view and the control of the multi-detector orbit. The main technical approach is to optimize the design of the optical structure and adopt a multi-tracking track design.

3.7 Platform vibration and compensation technology

The attitude disturbance and orbital positioning accuracy of the platform will affect the initial orientation of the visual axis of the laser communication system and the open-loop capture uncertain area, which will affect the capture time and capture probability. Compared with different platforms, the technical difficulties of different platforms will also have certain differences, such as the diversification of platform attitude parameters and the complexity of platform vibration factors. Then the main technical approach is to pass the low-frequency disturbance, and adopt the attitude detection technology. For high-frequency vibration, coarse and fine composite shaft control technology can be used.

3.8 Space adaptation technology of components

In general, the space environment will directly affect every component in the space laser communication system. The main influencing factors are vacuum environment, cold black environment, background light radiation, particle radiation and space plasma, which will directly affect every component in space laser communication system, which is analyzed from optical surfaces and mechanical structures, electronics and optoelectronic devices respectively.

For optical surfaces and mechanical structures, the technical difficulty lies in the mirror surface performance protection technology, so the solution is to use high-performance radiation-proof materials for the mirror. The mating material which is not prone to cold welding shall be selected for the mechanical component. Then for electronics and optoelectronic devices, the technical difficulty lies in preventing the output power of the laser light source from falling, and suppressing the attenuation of the amplifier gain. The solution is to use a seed light source with strong radiation resistance, adopt an anti-static design for the circuit and the electronic device, and also need to strengthen the circuit and the electronic device.

4. Conclusion

At present, key technologies of space laser communication mainly include high-quality optical system design technology, high-precision capture alignment tracking technology, compensation technology influenced by atmospheric channel, high-speed and high-power launch technology, high-sensitivity and low-error detection technology, one-point to multi-point communication technology, platform vibration and compensation technology, and space adaptation technology of components, which can provide reference for relevant personnel.

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