Feasibility study of microsatellite laser communication pointing system based on SEEOR technology

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Abstract: Satellite laser communication technology is a communication method that uses laser beam as information transmission carrier to transmit information data in space. It has many advantages such as large communication capacity, long transmission distance, high bandwidth, no spectrum permission, etc. At present, the antenna light direction of its typical satellite laser communication system is realized by rough tracking servo turntable platform carrying optical components, so there are a series of shortcomings such as turntable vibration, corner error and system inertia etc. Currently, a new technology, Non-Mechanical Beam Steering (NMBS) technology, in mid-wave infrared (MWIR) which has emerged, is expected to break through above shortcomings and provide possibilities for the transmission of beacon light in satellite laser communication. This paper focuses on the application of non-mechanical beam pointing technology in satellite laser communication system. We objectively analyzed the basic principles of the Non-Mechanical Beam Steering chip work, and the feasibility of using Non-Mechanical Beam Steering to transmit beacon light in satellite laser communication theoretically. It will open up a new way for the development of microsatellite laser communication technology in the future.

1. Introduction

Satellite laser communication technology is a communication method in which a laser beam is used as a carrier for information transmission and information data is transmitted in space. The microwave bandwidth currently used for satellite communication is often in the 100-megabit class, and the maximum is the G-bit level, but now people are increasingly unsatisfied with the requirements of communication technology\cite{1}.

The laser communication technology has a series of advantages such as large communication capacity, long transmission distance, high bandwidth, no spectrum permission, and good confidentiality etc. Compared with the existing microwave communication means, the microsatellite laser communication has larger communication capacity and data transmission. The high rate, small size of the transceiver system, good confidentiality and anti-interception, strong anti-electromagnetic interference capability, flexible networking and other advantages. Microsatellite laser communication is completed by two systems: laser communication system and ATP. ATP is mainly to capture, track and align the laser communication terminals, and overcome the interference of the laser communication terminal carrier itself to maintain the alignment state. Thereby ensure reliable and stable operation of the laser communication link. The microsatellite laser communication system must
align the transmitting end with the receiving end before data transmission, which is the premise for realizing space laser communication. The satellite at the transmitting end uses a very narrow beacon optical laser beam to align with another satellite receiving end at a very long distance, so that the other party receives the satellite position information of the transmitting end, and it is very difficult to achieve accurate docking. Therefore, the compact and precise ATP tracking turntable is an important part of the microsatellite space laser communication.

The role of the tracking turret in the laser communication system is to achieve the precise pointing of the optical axis, that is, the accurate aiming of the beacon light in the microsatellite laser communication is realized by the mechanical turntable. After comprehensive analysis of the turntables used by each communication terminal, it is found that most of the turntables are two-axis positioning devices. The technical parameters of the turntable are the satellite working track height, environmental characteristics, vibration characteristics, servo control, load deformation, system power consumption, and structure. The technical requirements of the modal and shafting accuracy are determined by a series of technical conditions, and the technical difficulties are met, and meeting these requirements is very demanding. SEEOR (Steerable electro-evanescent optical refractor) is a non-mechanical beam control technology. The microsatellite laser communication pointing system based on "SEEOR" technology can theoretically realize the accurate pointing of beacon light without relying on mechanical turntable. Many shortcomings of the traditional ATP platform have broad development prospects.

Figure1. Schematic diagram of laser communication in satellite space

1.1. SEEOR technology
Scientists of the US Naval Research Laboratory (NRL) have recently demonstrated a new chip-based non-mechanical beam steering technology called "SEEOR for Steering Electronic Rejectors (SEEOR)" that requires no mechanical equipment. The output direction of the input medium-wave infrared (MWIR) laser can be controlled in two dimensions, which provides greater steering capability and higher scanning speed than conventional methods. Which can replace expensive, cumbersome, reliable and inefficient mechanical universal joint laser scanning heads.

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Figure 2. Steerable electro-evanescent optical refractor (SEEOR) chip
The NMBS technology based on an architecture first proposed by Vescent Photonics[3,4] and now being developed at the Naval Research Laboratory (NRL), which is the steerable electro-evanescent optical refractor (SEEOR). The SEEOR technology, which has been matured in the short-wave infrared (SWIR) band and demonstrated in the near infrared successfully, which is based on a slab waveguide design with light mainly confined in a passive high-index core and transiently coupled into a tunable LC upper cladding. A voltage applied to the LC which changes its refractive index, so modulating the effective index of the waveguide. Elaborate design of the electrodes and substrate tapers permit this index change to be interpreted to high speed and consecutive steering in two dimensions.

Figure 3(a) shows a cross-sectional view out-of-plane steering; the electrodes above the out-coupling region allows control of the voltage applied to the LC in order to adjust the effective index of refraction in the waveguide, thereby creating a variation in angle in the substrate, resulting in a change in the out-of-plane angle at the substrate exit facet. Figure 3(b) is a top view showing in-plane steering; the prismatic electrode changes the LC index in the triangular region, resulting in an in-plane angular deviation. Figure 3(c) shows the extended cross section near the output surface. Light is primarily confined to the core and is increasingly coupled to voltage-tuned LC. The conical cladding causes optical coupling back into the substrate in the conical region. Figure 3(d) shows a schematic graph of the encapsulated SEEOR. SEEOR equipments have proved: up to 270° of 1D steering; The angular field of regard (FOR) is up to 50°×15° for steering in 2D; and high speed (60 kHz). In addition, they are compact (-6 cm³) and have low power requirements (only mW)[3,4].

Continuous NMBS in the mid-wave infrared (MWIR) has been demonstrated. In order to accomplish this, a SEEOR that relies on chalcogenide glass for the subcladding and waveguide core was designed and fabricated. The tapered subcladding was deposited using a shadow deposition mask. Some experiments demonstrate that a chalcogenide glass subcladding with a near-linear taper outline can be deposited without evolving significant microstructure in the thinner section of the taper, therefore, which can complete the SEEOR two-dimensional steering.

The device is characterized by small size, light weight and low power consumption, and has continuous steering capability, which provides a promising technical path for MWIR beam steering technology. MWIR band mapping shows great potential in many applications, such as chemical sensing, monitoring of material emissions from waste disposal sites and other industrial facilities, and has been applied in non-mechanical steering technology for foreign object detection in driverless cars.

2. Application of SEEOR technology in micro-satellite laser communication system

2.1. light source
In order to meeting the requirements of miniaturization and low power consumption of laser communication terminals between satellites, semiconductor lasers are generally used as light sources of...
signal light and beacon light with a wavelength of 800nm. However, in recent years, due to the continuous maturity of technology, some satellite optical communication systems have adopted the wavelength of 1550nm as the light source. Previous work has demonstrated that the non-mechanical beam steering technology uses short-wave infrared and near-infrared waveguides, of which the short-wave infrared laser wavelength is 1000~3000nm, which is in line with the laser communication requirements for the wavelength of 1550nm.

2.2. Workflow
The typical microsatellite laser transmitting optical path includes two optical channels: beacon light transmitting and signal light transmitting. The beacon light output end and its beam shaping lens group constitute the beacon light transmitting channel, and the large beam divergence angle continuous light output is carried out in the acquisition process of laser link establishment. Until the beacon light is finally captured by the receiving side of the satellite field of view. Typical satellite terminal transceiver workflow is shown in figure 4. The satellites of both sides start to seek laser communication, and the servo turntable is restored to zero under the control of the servo system. The rotary table control system can roughly calculate the position parameters of another satellite terminal according to the ephemeris, and control the rotary table to make the corresponding azimuth and pitching rotation, so that the rotary table coarse tracking visual axis points to the receiving end; The receiver also points the optical axis to the satellite at the transmitter and starts to capture the beacon optical signal. If the acquisition is successful, both parties continue to carry out stable tracking mode and prepare for laser communication. The difference lies in that the beacon light does not need the mechanical turntable to point the visual axis to the other side, but directly uses the “SEEOR” technology to point the beacon light directly to the receiving end, and there is no pointing accuracy error caused by the vibration characteristics of the mechanical turntable, servo control, shaft precision and platform inertia. After the receiver successfully captures its own beacon light signal, the turntable servo system directly adjusts the turntable for rough and fine tracking process, and finally completes the data transmission. It greatly shortens the docking time, improves the pointing accuracy and conforms to the laser communication workflow.

2.3. Beam adjustment range
We select a common classic turntable can realize the azimuth and pitching direction of rotation range respectively is ±60° and ±11°, but because of the light passing through a reflection mirror can enter in the optical system, according to the law of reflection, the Angle of reflection equals the Angle of incidence, so, if applying an SLR lens structure of turntable, azimuth and pitching direction scope of work is only half of the light adjusting range, which is the scope of the turntable bearing rotation ±30 °, pitching rotation range is ±6 °. In SEEOR, SEEOR equipment theoretically can be as high as 270 ° I D steering; An angular field of regard (FOR) up to 50° × 15° is used for 2D steering [5], which can fully meet the general beam adjustment range. According to the data show that SEEOR equipment has been able to achieve the maximum of 14 ° plane and 0.6 ° out-of-plane turned, also can satisfy the requirement of beacon light part to [2]. As SEEOR continues to evolve rapidly, it is anticipated that SEEOR will eventually meet the range of beam angles used.

2.4. Pointing accuracy
According to the known pointing accuracy of microsatellite laser communication[7], the optical axis pointing error less than 150 rad is a commonly used and easily accepted technical index[8,9]. SEEOR technology, successfully demonstrated in near-infrared, is based on a planar waveguide design in which light is confined primarily to an inner passive-high refractive index core that is gradually coupled to a tunable LC upper cladding. The voltage applied to LC changes its refractive index, thereby
modulating the effective refractive index of the waveguide. Careful design of the electrode and substrate taper allows this exponential change in two dimensions to translate into high speed and continuous steering. Because there is no rotary table vibration characteristics, servo control, load deformation, structural mode and shaft accuracy and other error factors, SEEOR technology beam pointing accuracy is certainly better than 150 μrad.

2.5. Power consumption
SEEOR technology consumes power at the milliwatt level, while a typical micro-satellite laser communication system requires the servo system to control the whole mechanical rotary table to realize the orientation of the visual axis, which consumes more power[10]. SEEOR technology greatly reduces the loss of satellite energy and greatly improves the service life of the satellite.

3. Conclusion
Up to now, the mechanical turntable and other equipment usually used in the light pointing process of the known microsatellite laser communication beacon are large in size[11,12], slow in speed, large in power consumption and prone to mechanical failure[13-15]. SEEOR is a non-mechanical beam control technology, capable of continuous angle adjustment in MWIR[5]. These devices, which are based on refracting electro-optical waveguides, provide two-dimensional angular steering without relying on moving parts. This paper proposes for the first time that it is feasible to apply "SEEOR" technology in satellite laser communication, which can greatly shorten the work flow of satellite acquisition and reduce the impact of errors caused by mechanical rotary table, such as vibration characteristics, servo
control, load deformation, system power consumption, structure mode and shaft accuracy on pointing accuracy. Although "SEEOR" technology is still immature and defective, its expansive application prospect in the field of space laser communication is still worth our expectation.

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