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High Speed Inter-Satellite Optical Communication

Dr. C Rangaswamy[1], Gireeshma A S[2]

Assoc.Prof, Department of Electronics and Communication, SJC Institute of Technology, Chikkaballapura, India[1]

Student, Department of Electronics and Communication, SJC Institute of Technology, Chikkaballapura, India[2]

Abstract: Satellite communication systems are increasingly more used by the society in many applications, and its development is a high priority for the scientific community. The need for increasing bandwidth to satisfy the users' needs, makes inter-satellites Free Space Optics (FSO) communication preferred instead of traditional radio frequency links. The inter-satellites communication links with high bit rates and low power is a determining factor in the performance of these systems. As such communications occur over long distances and high altitude orbits, optical sources with highly collimated and coherent beams are needed in order to ensure a better link between the transmitter and the receiver with low emission power. This paper involves the development of two experimental blocks for implementing an inter-satellite optical communication system using a semiconductor laser type. It aims at the definition and analysis of the elements of the two circuits, at the transmitter subsystem and includes the design for the production of printed circuit boards (PCB). Moreover, experimental tests were performed to validate the results obtained in the simulations.

Index Terms—Satellites, Optical Communications, Transmitter Subsystem, Semiconductor Laser.

I. INTRODUCTION

Optical inter-satellite communication has been attract- ing worldwide attention because of the growing need forlarger capacity and higher speed transmissions of ob- servation data thanks to the recent improvements in the performance of Earth observation satellites and because of its features such as not needing the frequency coor- dination and the ease in which confidentiality is ensured compared to radio frequency (RF) communication. Also in Japan, since the first success of space optical commu- nication experiment in 1994, research and development(R&D) continues in this area even now in 2021.

NEC hascultivated its optical inter-satellite communication tech- nology through the development of optical communica- tion systems such as the optical inter-orbit communi- cations engineering test satellite (OICETS) called Kirari launched by the Japan Aerospace Exploration Agency (JAXA) and the optical communication systems such as small optical transponder (SOTA) of the National Insti- tute of Communications and Technology (NICT).This paper introduces a future space system based on optical inter-satellite communication as well as the features and technologies of the laser communication terminal for satellites developed for JAXA's optical data relay and earth observation satellites.

II. METHODOLOGY

Features of Optical Inter-satellite Communications

Traditional inter-satellite communication uses radio frequencies (RF). With this method of communication, however, interference has to be avoided, so it has var- ious limitations. Also, it is hard to achieve high-speed communication due to limited bandwidth.

Compared to RF communications, high-speed, high-capacity optical inter-satellite communications can be achieved because of its high frequency carrier wavesand large bandwidth. Another important feature is that it is not affected by radio interference. Also, optical an- tennas can be smaller and lighter than RF antennas, because their short wavelengths provide high energy and high gain even with a small antenna diameter. The weight reduction of a satellite is a great advantage be- cause launch costs are then greatly reduced.

Optical inter-satellite communications use a very nar-row beam, which needs high accuracy pointing, acqui- sition and tracking technology for communication links. This feature makes it more advantageous than RF com- munications for security reasons (**Fig. 2**). On the other hand, optical inter-satellite communications must cover very long distances, so the use of very narrow beams makes it extremely difficult to provide enough irradiance to shine the laser beam to the other

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satellite. Also, to deliver the light to the other satellite, it is necessary to have a high-power optical amplifier that can operate

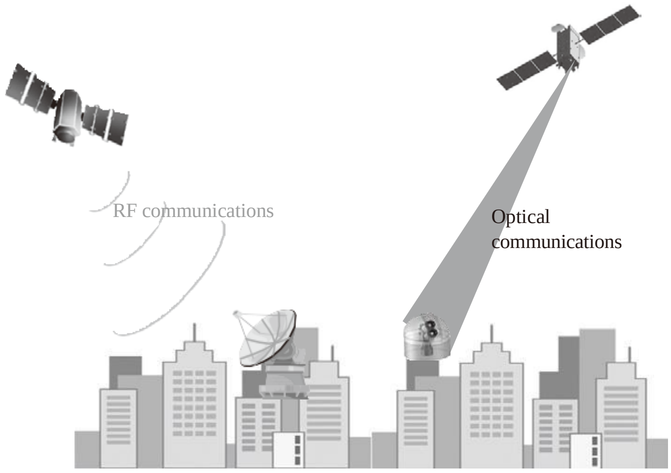

Fig. 2 Difference in beams.

stably even in the vacuum environment of space and can detect weak light from the other satellite.
Considering these issues, optical inter-satellite com- munications must support ultra-long-haul communica- tions. Section 4 introduces the technologies developed by NEC under the guidance of JAXA.

Overview of Optical Inter-satellite Communication Technology
Optical acquisition and tracking technology

In optical communications in space, the laser beam plays two roles: as a means of establishing a link and as a carrier wave for communications.

Optical acquisition and tracking technology is necessary to establish this link.
Information on the locations of the two communicat- ing satellites can be predicted to a certain degree using orbit calculations, but the information obtained is not accurate enough and may be affected by thermal distor- tions and micro vibration in the spatial environment. As a result, it is essential to have a technology that allows both parties to scan the transmitted laser beam and, at the same time, receive, locate, and track the laser beamfrom the partner satellites.

In the optical capture operation, the laser beam is first scanned in the expected direction of the communication partner satellite. The partner satellite detects that laser beam with its own optical acquisition sensor to deter- mine the exact position of the other satellite and emits a laser beam in that direction. As a result of both satellites performing these operations, the satellite will eventuallytrack the laser beams from the other satellite and con- tinue to shine the laser beams. NEC has developed an algorithm for the acquisition and tracking of the communication partner satellite with certainty in a short period of time. This algorithm uses multiple scan shapes depending on the sequence and narrows the scan area for each scan to improve the ac- curacy. **Fig. 3** shows an image of a spiral scan between a satellite in geostationary orbit (GEO) and one in low earth orbit (LEO). This spiral scan, one of the possible

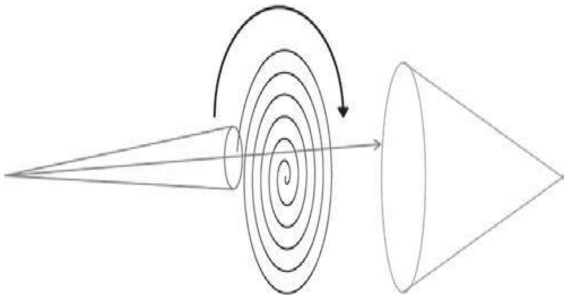

Fig. 3 Image of spiral scan.

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scan shapes, is capable of scanning a wide acquisition area at high speeds. Other scan shapes include the ras- ter scan and the random scan. Each of them has its own characteristics depending on the sequence.

Optical transponders with amplifiers and modems

The distance between a geostationary satellite and an earth observation satellite is 40,000 km. The signal light is attenuated by beam diffusion during long-distance propagation and the Doppler frequency shift is generat-ed by the relative position change between satellites. To secure the communication quality required with such a weak, unstable signal light, NEC has reinforced the al- ready proven 1.5 µm band optical fiber communication technology for the space environment. The configuration of the optical transponder is shown in **Fig. 4**.

The main feature of the transmitter section is the high-power optical amplifier (amp). It uses an erbium doped fiber amplifier (EDFA) similar to those used in fi- ber-optic communications, but is implemented in a com- plicated manner to ensure high power characteristic andlong-term reliability in the high vacuum environment where waste heat is ineffective. It also calculates the magnitude of the Doppler frequency shift in real time based on the orbit information and feeds it back to the transmitting light source.

On the receiving side, the low-noise characteristics over a wide temperature range, a digital signal processor with accurate demodulation even when it is buried in noise light, and error correction codes are noteworthy features in the responder section. By applying the best of optical fiber communication technology to these components, high-speed signal transmission of 1.8 Gbps has been achieved.The resistance to vibration/shocking, vacuum/high- temperature environments, and radiation that is necessary for the communications system we helped develop as part of the equipment onboard the satellite was confirmed through long hours of stringent testing.The development of optical communication equipment

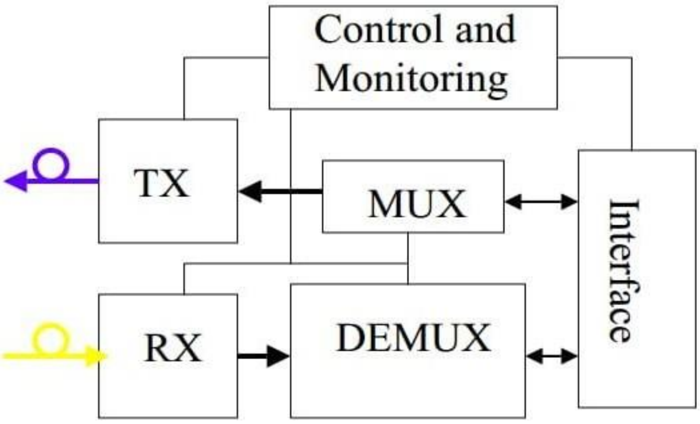

Fig. 4 Configuration of optical transponder.

for use onboard the satellites requires a wide variety of technologies. This project moved forward thanks to col- laboration between two divisions: the Ground Communi- cations System division that possesses the technology for 1.5 µm optical fiber communications and the Space Sys- tems division that possesses the technology for adaptingto the space environment and ensuring reliability.

Beginning of Onboard Service of Optical Inter-satellite Communications

Under the guidance of JAXA, NEC has developed threesets of laser communication terminal, including one for a geostationary satellite and two for earth observation satellites. Among them, the system for geostationary satellite was installed in the optical data relay satellite launched in November 2020. The system succeeded in establishing an optical communications link between the satellite and an optical ground station located approx- imately 40,000 km away. This achievement is the first step toward the onboard service of an optical inter-sat- ellite communication system in Japan.**Fig. 5** shows the configuration of the developed laser communication terminal.NEC's laser communication terminal employ the 1.5 µm band wavelength, which is widely used in underwa- ter cables and LANs and also has excellent parts avail- ability. The inter-satellite transfer rate of 1.8 Gbps is at the world's top level and more than seven times faster than conventional radio wave communications

In the near future, we plan to demonstrate and practi- cally use optical inter-satellite communications Between

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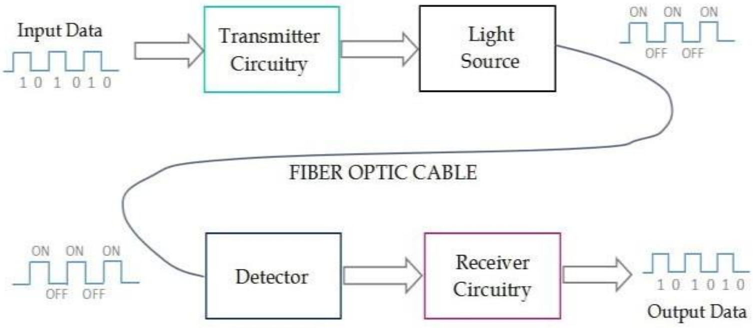

Fig. 5 Configuration of optical communication system.

the optical communications equipment onboard the advanced land observing satellites ALOS-3 and ALOS- 4, which will be launched in FY2021 or later. Also, NEC is developing next-generation optical communication technologies to support the sophistication of optical communication networks, such as multiple access, and to achieve smaller, lighter and faster transmission rates.

VI. CONCLUSIONS

This paper aimed at describing the optical transmitter subsystem, describe the two circuits considered, simulate the circuit in the low frequency range, designing the printed circuit boards for the two circuits and, finally, to perform experimental tests. It was found that the FP lasers, despite having a simple structure when the size of its cavity decreases the size can obtain a behavior of a single mode laser. In this way, we used a laser FP of heterogeneous structure, AlGaInP, to establish communication on both circuits used.

In conclusion, the results obtained, were satisfactory. The main problems were the differences in the parameters of the components of PSpice simulator and experimental trials, which did not present similar results. Another problem was the inability of some electronic equipment, to operate at higher frequencies specially the signal generator and the breadboard.We were able to design a circuit with integrated components to address these constraints, whose trial is only possible with a circuit plate printed, given that those embedded MAX3643 and DS1865 have small dimensions and are of a technology (TQFN) which requires it.The realization of this dissertation has allowed not only to acquire a wide range of knowledge in the area of optical communications optic between satellites, but also to apply the concepts that were obtained in course units over the past few years in the Military Academy and more recently at the Instituto Superior Técnico. This paper has presented NEC's approach toward op- tical inter-satellite communications and related technol- ogies, In the future, NEC will continue to develop and demonstrate the technology, with the aim of contribut- ing to society.

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