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Laser communication experiments with a geostationary satellite from a ground telescope

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The Main Astronomical Observatory of the NAS of Ukraine is currently developing all necessary hardware to perform laser communication experiments between its 0.7-m telescope and the ARTEMIS satellite. Laser communication equipment will be installed in the Cassegrain focus of the AZT-2 telescope. Continuing the previous developments dealing with receiving and transmitting channels, the acquisition and tracking systems are now being developed, as well as a turbulence compensation system, which will reduce the pointing errors during the communication with ARTEMIS. The description of the performed work and some test results are given in the paper.

INTRODUCTION

The ESA telecommunication satellite ARTEMIS was launched on July 12, 2001. It is located in a geostationary orbit (21.5° East) and equipped with RF terminals (in L-band, S-band, Ku-band and Ka-band) and a laser communication terminal (LCT). The LCT communicates with a similar LCT onboard the low Earth orbiting (LEO) satellite SPOT-4. The optical data relay system onboard ARTEMIS, called Semiconductor Laser Inter Satellite Link Experiment (SILEX), operates at 2 Mbps in transmission and at 50 Mbps in reception. On November 21, 2001 ESA successfully performed the world first laser communication experiments between the LEO satellite SPOT-4 and ARTEMIS [10]. Laser communication between OICETS satellite (JAXA, Japan) [11] and ARTEMIS (ESA) were successfully performed in 2006.

Since 2003 laser communication experiments between ESA's Optical Ground Station (OGS), located at the Teide observatory, and ARTEMIS are regularly performed [1, 8, 9]. These experiments investigate the influence of atmospheric turbulence on laser beam propagation. In 2007 successful laser communication was performed by Astrium, France, between an airplane and ARTEMIS in the experiment called LOLA.

For future laser communication between ground telescopes and spacecraft in Earth orbits and in orbits around the Moon and Mars [2] it is important to continue the investigation of influence of atmosphere on laser beam propagation and to compare results from different atmosphere regions. This can be done by using different ground telescopes, for example, ESA's OGS (Canary Islands, h = 2400 m) and the Main Astronomical Observatory (MAO), Ukraine (h = 190 m).

In 2001, MAO investigated the possibility of laser communication experiments between ground telescopes and ARTEMIS and contacted the telecommunication department of ESA. MAO is equipped with several telescopes and has experience in distance measurements from its laser ranging station to LEO satellites.

In 2002, ESA experts visited MAO and discussed the possibility to perform laser communication experiments using MAO equipment. It was concluded that it would be interesting to compare laser link experiments of ESA's OGS (h = 2400 m, Atlantic region) with experiments performed in Kyiv (h = 190 m, Continental region).

According to the meeting agreement, MAO developed the equipment to be used in laser communication experiments with ARTEMIS in the Cassegrain focus of an astronomical telescope with a small amount of support from the National Space Agency of Ukraine (NSAU) [4—6].

An astronomer from MAO was invited by ESA to visit the OGS in 2004. He participated in laser communication links with ARTEMIS.

MAO is currently developing all necessary hardware to perform laser communication experiments between its 0.7-m telescope and ARTEMIS satellite. The laser communication equipment will be installed in the Cassegrain focus of the AZT-2 telescope. Currently, the acquisition and tracking system is being developed. ARTEMIS is a geostationary satellite with high inclination (its position on the sky is currently fluctuating by ±5.8° in North-South direction) so that active tracking is necessary.

In addition, MAO is developing a turbulence compensation system that will reduce the pointing errors during the laser communication with ARTEMIS. The detailed description of the work being performed is given in the report.

PREVIOUS MAO DEVELOPMENTS

The Main Astronomical Observatory of Ukraine plans to use the reflector-type telescope AZT-2 for laser communication with ARTEMIS. The equipment is going to be implemented in the Cassegrain focus of the telescope. The primary telescope mirror has a diameter of 700 mm and the secondary hyperbolic mirror of 215 mm. The focal length of the Cassegrain system is 10500 mm. The AZT-2 telescope is equipped with a refractor guiding telescope with an aperture of 200 mm in diameter and a focal length of 2500 mm.

For several years the preparations for the laser communication experiments with ARTEMIS have been ongoing. We first developed the receiving and transmitting parts of the communication system.

According to our calculations and data provided by ESA, the density of the power of laser communication signal coming from the satellite to the Earth's surface (taking into account the standard absorption of the atmosphere at the angle of 60° to zenith) is about 35 nW/m^2 in the spectral region of 816—823 nm. The receiving data rate is 2048 kbit/s. For the given spectral band an avalanche Si-photodiode (APD) is used. APD ensures the intrinsic amplification of signal and the possibility of operation in the photon-counting mode. We achieved receiver sensitivity of 0.15 nW in frequency band of 8 MHz. The detailed description of the receiving channel using an APD is presented in previous publications [5, 6].

The ground station must transmit an optical beam with a data rate of 49.4 Mbit/s in the spectral region from 843 to 852 nm and must ensure an irradiance of 90 nW/m^2 (at the geostationary satellite). The laser transmitting module that was developed produces a transmit peak power of up to 200 mW with a modulation current of up to 350 mA.

All laser radiation which is being send to ARTEMIS should have the left-hand circular polarization (LHCP) with a deviation less than 2.5 % from the ideal LHCP. We use a quarter-wave plate in the spectral region of 800—900 nm for the transformation of linear polarization of laser beam into the required LHCP. An extended description of transformation and measurement equipment is presented in [7]. We achieved the deviation less than 1.7 % from the ideal LHCP. Furthermore, we performed an investigation in atmosphere conditions in the direction towards ARTEMIS [3].

SCHEME OF ORIENTATION

If laser communication is performed between a ground optical station (telescope) and a geostationary satellite, the time delay T_d of signal between received and transmit signals appears (Fig. 1).

Time delay is determined by the equation: $T_d = 2L/C$, where L ° is the distance from the ground station to the satellite. In our case L = 38000 km, T_d = 0.253 sec. The angle θ_v between the visible position of the satellite and the direction of sent

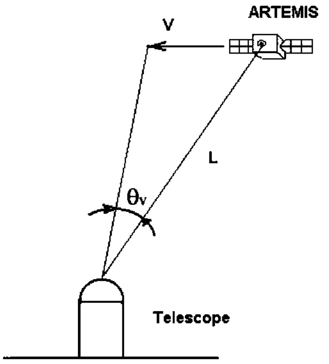

Fig. 1. Scheme of time delay of propagation of laser signals and cone effect

signal is determined by the equation:

$$\theta_v = 15''\cos\delta, \qquad (1)$$

where δ is the angle of inclination of the satellite on the sky. The OGS of ESA has the following coordinates: Longitude 16.5101° W, Latitude 28.2995° N and Altitude 2393 m. The coordinates of MAO are the following: Longitude 30.4967° E, Latitude 50.3642° N and Altitude 190 m. ARTEMIS is a geostationary satellite whose inclination is not controlled. Its deviation is 5.8° from the nominal declination of $\delta = -7°17'''$. According to equation (1), the angle between the receiving and transmitting direction of the laser beams vary between 3.7 arcsec and 3.8 arcsec, which is the so called point ahead angle. For the maximum deviation of $\theta_v = 3.8$ arcsec the distance between laser beams is determined by the equation: $d_L = 2L\cdot\sin(\theta_v/2)$. For $L = 38000$ km, $d_L = 0.7$ km.

The diameter of laser beam has to be optimized for the concrete place of the link with the satellite. The diameter of laser beam spot with a beam divergence of 1 arcsec at the level of ARTEMIS is 166 m. An error of 0.5 arcsec in value of θ_v is significant for the density of communication signal.

The situation is similar in astronomical guide star systems where an artificial laser star in the upper atmosphere is used. In the common case the cone effect exists, where the light from the guide star and the observing star move through different air masses [12].

ACQUISITION AND TRACKING SYSTEMS

MAO is currently developing the acquisition and tracking system for laser communication experiments with ARTEMIS.

The optical pointing scheme for acquisition of the ARTEMIS satellite is shown in Fig. 2. An accuracy of coordinate position of the telescope is two angular minutes. The CCD_1 camera (2000×3000 pixels) was used with a wide angle Maksutov objective ($D = 10$ cm, $F = 1$ m). This camera can work with short time exposures of up to 30 sec or more. The CCD_2 camera (795×596 pixels) works at the guiding telescope ($D = 20$ cm, $F = 2.5$ m) and transmits the image to the computer, where it is recorded and displayed. The CCD_3 camera is planned to be used in Cassegrain focus of 0.7-m telescope ($F = 10.5$ m). It could be TV or faster frame rate CCD or CMOS camera. The signals from the CCD_3 camera could be analyzed by the computer for precise correction of the telescope tracking along α, δ coordinates.

The acquisition and tracking system works in micro-step regime with the computer step of correction $\omega = 0.003$ arcsec/s and maximum speed of correction up to 4.6 arcsec/s. The step regulation is possible directly from block of correction situated near the telescope. Also it is possible to correct the movement of the telescope using the RS-485 interface in remote mode.

We tested the acquisition system by performing the observation of group of ASTRA-1L, ASTRA-

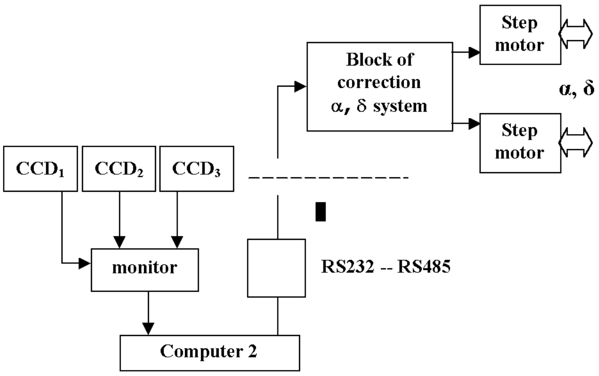

Fig. 2. The optical pointing scheme

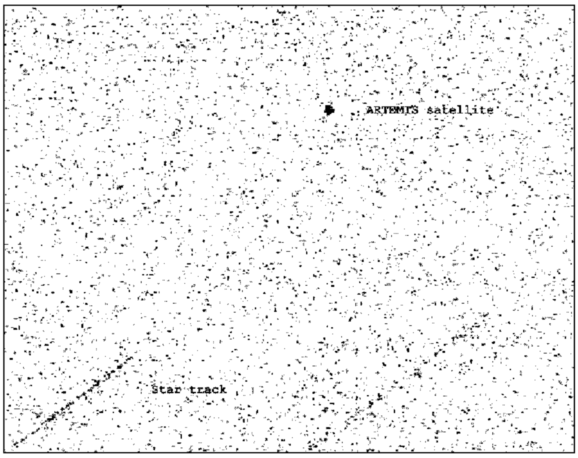

Fig. 3. ARTEMIS geostationary satellite at 21.3° E

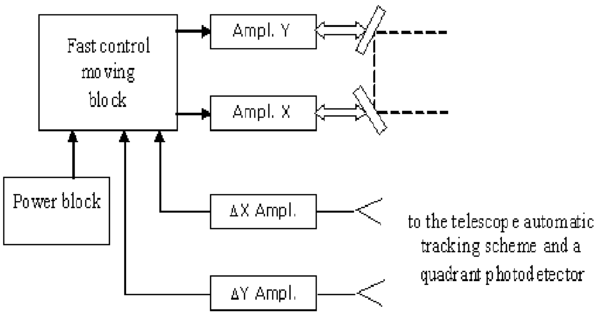

Fig. 4. Block scheme of turbulence compensation system

1KR, ASTRA-1H, ASTRA-1G, ASTRA-1F and ASTRA-1E geostationary satellites. The CMOS camera (30 s exposition) was used. ARTEMIS satellite’s speed is approximately up to 2 arcsec/s. The first observation of ARTEMIS was performed without the tracking correction system. This observation let us calculate the required speed of correction.

Fig. 3 shows the ARTEMIS satellite image with enabled correction system (CMOS camera, 30 sec exposition). At the time of observation ARTEMIS speed was 1.17 arcsec/s. The analysis of ARTEMIS picture led us to the result that real trace accuracy of correction system is less than 1 arcsec/s.

AUTOMATIC TELESCOPE TRACKING ALONG α AND δ COORDINATES. ATMOSPHERE TURBULENCE COMPENSATION

For the precise guiding of the ARTEMIS satellite it would be better to have an automatic tracking telescope system (ATTS) along α and δ coordinates.

Some elements of ATTS can be used in turbulence compensation devices. In simple case these devices can use tip/tilt mirrors with piezoelectric or electromagnetic actuation.

ATTS has a quadrant photodiode with preamplifiers, differential amplifiers, and filters. The signals from these filters are used by the turbulence compensation system and by other filters of ATTS. After that the signals are digitized and processed by a microcomputer. The digitized signal can also be used by the tracking system to track the satellite.

The output signals of tracking scheme go into the turbulence compensation system (Fig. 4). This system has the amplifiers and the fast moving mirrors for compensation of position of turbulent moving image along X and Y coordinates.

CONCLUSIONS

The result of our calculations and previous experiments from ESA’s OGS show that the laser communication link with ARTEMIS requires a laser beam divergence of ≤ 2 arcsec. Such a small divergence requires precise tracking of the geostationary satellite and the implementation of a point ahead angle between the transmit and the receive beams.

We have developed and tested an acquisition and tracking system for our 0.7-m astronomical telescope, which performs the tracking of the geostationary satellite with a maximum speed along α and δ coordinates of up to 4.6 arcsec/s. The tracking speed resolution is 0.003 arcsec/s.

Our workgroup is also developing a turbulence compensation system, which operates with a quadrant photodetector and an auto-tracking system. The turbulence compensation system will reduce the pointing errors during the laser communication with ARTEMIS.

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REFERENCES

1. Alonso A., Reyes M., Sodnik Z., et al. Performance of satellite-to-ground communications link between ARTEMIS and the Optical Ground Station // Proc. SPIE.—2004.—**5572**.—P. 372—383.
2. Khatri F. I., Boroson D. M., Murphy D. V., at al. Link analysis of Mars-Earth optical communications system // Proc. SPIE.—2004.—**5338**.—P. 143—150.
3. Kuz'kov V., Andruk V., Sodnik Z., et al. Investigation of Atmospheric Instability for Communication Experiments with ESA's Geostationary Satellite ARTEMIS // Kinematics and Physics of Celestial Bodies. Suppl.—2005.—N 5.—P. 561—565.
4. Kuz'kov V. P., Medvedskii M. M., Yatskiv D. Ya., et al. Preparation for optical Communication Experiments with the Geostationary Satellite ARTEMIS // Kosmichna Nauka i Tekhnologiya.—2003.—**9**, N 4.—P. 79—83.
5. Kuz'kov V. P., Nedashkovskii V. N. Receiving system for ground-space laser communication // Kosmichna Nauka i Tekhnologiya. Suppl.—2003.—N 2.—P. 106—109.
6. Kuz'kov V. P., Nedashkovskii V. N. A Receiver with an Avalanche Photodiode for the Optical Communication Channel from a Geostationary Satellite // Instruments and Experimental Techniques.—2004.—**47**, N 4.—P. 513—515.
7. Kuz'kov V. P., Nedashkovskii V. N., Savenkov S. N., et al. Investigation of the polarization of the laser transmitting module for communication experiments with the geostationary satellite ARTEMIS (ESA) // Kosmichna Nauka i Tekhnologiya.—2006.—**12**, N 1.—P. 23—28.
8. Reyes M., Alonso A., Sodnik Z., et al. Ground to space optical communication characterization // Proc. SPIE.—2005.—**5892**.—P. 1—16.
9. Reyes M., Sodnik Z., Lopez P., et al. Preliminary results of the in-orbit test of ARTEMIS with the Optical Ground Station // Proc. SPIE.—2002.—**4635**.—P. 38—49.
10. Tolker-Nielsen T., Oppenhauser G. In-orbit test result of an operational optical inter satellite link between ARTEMIS and SPOT4, SILEX // Proc. SPIE.—2002.—**4635**.—P. 1—15.
11. Toyoshima M., Yamakawa S., et. al. Ground-to-satellite optical link tests between the Japanese laser communication terminal and the European geostationary satellite ARTEMIS // Proc. SPIE.—2004.—**5338**.—P. 1—15.
12. Renaud F. Laser guide stars: principle, cone effect and tilt measurement // Proc. NATO Advanced Study Institute on Optics in Astrophysics. Cargese, France, 16—28 September 2002. — Berlin: Springer, 2005.—P. 249—273.—(NATO Sci. Ser. II. Mathematics, Physics and Cemistry.—Vol. 198).

ЛАЗЕРНІ КОМУНІКАЦІЙНІ ЕКСПЕРИМЕНТИ МІЖ ГЕОСТАЦІОНАРНИМ СУПУТНИКОМ І НАЗЕМНИМ ТЕЛЕСКОПОМ

В. Кузьков, З. Соднік, С. Кузьков, Д. Воловик, С. Пуха

В даний час Головна астрономічна обсерваторія НАН України розробляє необхідне устаткування для проведення лазерних комунікаційних експериментів між телескопом та супутником ARTEMIS. Лазерне комунікаційне обладнання буде встановлене в кассегренівському фокусі 0.7-м телескопа АЗТ-2. Продовжуються попередні розробки приймального і передавального каналів, розроблено системи наведення, супроводу та компенсації турбулентності. Остання дозволить зменшити похибку наведення при комунікаційних експериментах. Наводиться опис здійсненої роботи і деякі тестові результати.