High-bit-rate Laser Space Communication Technology and Results of on-board Experiment.

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***Abstract*—This paper is devoted to laser data transfer experiment between ISS and on-ground terminal performed by "RPC PSI" and RKK "Energia". The description of used hardware, and experimental results are listed.**

***Keywords*—laser communication; ISS; experiment;**

I. INTRODUCTION (*Heading 1*)

During more than a half-century of space exploring history, humanity has launched a large amount of various type spacecraft into space. Today it seems usual to watch TV-programs transmitted from another hemisphere through satellite channels, to use precise space maps for navigation, obtaining your own coordinates with help of navigation satellites.

Requirements of modern economics for transmitted information volume and variety is constantly increasing. But now we need to struggle with some limitations.

Firstly space is limited on the orbits. On geostationary orbit left not much space for satellite installation, but mainly the radio range is too limited for communication between increasing satellite amount and constantly appearing new tasks which require wide bandwidth channels.

Secondly, new earth-observing satellite system's development for tasks of meteorology, earth mapping, natural resources control and reconnaissance is also limited by economical bounds while modern remote sensing space crafts are expensive in spite of their low efficiency. Modern optical and radar-locating means allow obtaining impressive volumes of information, but more difficult task is to transfer this volume to ground-based customer.

At present time, remote sensing spacecraft's information record time is about ten times less than this information transfer. For example, modern remote sensing optical/multi-spectral receiver's bandwidth is about 6 Gbits/s, and on-ground transmitting bandwidth is 0.3 Gbit/s. So the transmitting time for one pass is about 10 minutes, during this time we could transfer information volume recorded for:

$$0.3 \text{ Gbit/s} \times 600\text{s}:6\text{Gbit/s} = 30 \text{ seconds}.$$

Next transfer session could be at least after 1.5 hour when the satellite would be passing on-ground station. So the efficiency of remote-sensing spacecraft is less than:

$$30\text{s} : 5400\text{s} = 5{,}5\cdot 10^{-3} = 0{,}55\%.$$

If we would have an information transfer channel equal by bandwidth to information record, that will highly improve remote-sensing spacecraft efficiency. In this case only one spacecraft could solve tasks of dozens similar spacecrafts. So at present time in progressive countries high-speed laser information transfer systems are developed, such systems could allow to transfer gigabit information volumes with affordable size and mass of on-board hardware.

But high-speed information transfer in these type of systems is done by means of extreme narrow laser beam pattern (from 10 to 1 arc seconds), so one of the main tasks of laser space communication technology is mutual targeting of two recipients with sub-second precision.

II. EXPERIMANTAL HARDWARE

By "Research and production Company "Precision systems and instruments" OJSc (Russia, Moscow) together with Korolev Rocket and Space Corporation "Energia" an onboard laser communication terminal (BTLS) was developed. It's main task was to perform a laser communication space experiment on Russian segment of ISS. BTLS was delivered to ISS by Progress spacecraft

Fig. 1. BTLS-N.

BTLS includes an outer module (BTLS-N) (fig. 1) which is installed on ISS outer surface and inner module (BTLS-V) (fig. 2) installed inside the space station.

For targeting purposes 3 typed of detection hardware are used in BTLS-N:

- Search and target lock array detector with 2^0 field
- Quadrant detector with 35' field
- Tracking array detector wit 4,2' field

Hardware is installed inside base frame.

Fig. 2. BTLS-V.

In August 2011, BTLS-N was mounted on ISS board and connected to ISS power line and BTLS-V. On Fig. 3 the BTLS-N installation place is shown.

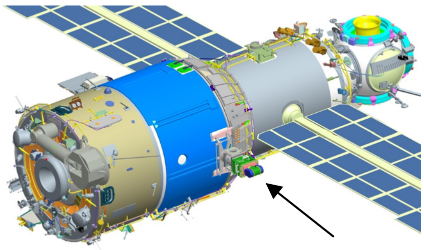

Fig. 3. BTLS Installation Site

For communication with on-board terminal and information transfer, an on-ground terminal NLT-1 was developed. This terminal was installed on "SON Arkhyz" optical observing station an North Caucasus. On Fig. 4 the optical-mechanical module of NLT-1 in dome is shown. Power, communication and control modules are installed in separate building.

Fig. 4. BTLS Installation Site

TABLE I. TECHNICAL PARAMETERS OF BTLS

Parameter	Value
BTLS-NLT-1 Communication line range, km	≤1000
Test information transfer bandwidth, Mbit/s	3,125,622
Data transfer bandwidth, Mbit/s	125
Communication session time, min	≤5
Information transceiver wave length, µm	1,55
Information transceiver power, W	6
Information receiver wave length, µm	0,85
Targeting system reference marks wave length, µm	0,81
Targeting system reference marks power, W	3
Targeting system receivers wave length, µm	0.78
Information transceiver beam divergence on -3Db, arc sec	60
Reference mark beam divergence on -3Db , deg	3.3
Target lock detector field of view, arc. min	35
Tracking detector field of view, arc min	4,2
Search and target lock detector field of view, deg	2
Information receiver field of view, arc min	3,5
Power consumption	≤300

TABLE II. TECHNICAL PARAMETERS OF NLT-1

Parameter	Value
Information transfer bandwidth, Mbit/s	3
Communication session time, min	≤10
Transceiver wave length, µm	0,85
Information transceiver power, W	≤10
Information receiver wave length, µm	1,55
Targeting system reference marks wave length, µm	0,78
Targeting system reference marks power, W	до 12
Targeting system receivers wave length, µm	0,81
Information transceiver beam divergence on -3Db, arc sec	60
Reference mark beam divergence on -3Db, arc min	10
Narrow field detector field of view, arc min	12X16
Wide field detector field of view, deg	3X3
Information receiver field of view, arc minП	1,2

III. SPACE EXPERIMENT RESULTS

Test experiment on BTLS-NLT-1 communication was performed on on-ground 18 km route at Arkhyz, Northern Caucasus. On one point of route NLT-1 terminal later used in space experiment was installed, on other point – BTLS. On this route were performed experiments on mutual system targeting and information transfer at 3, 125 and 622 Mbit/s bandwidth.

After BTLS installation on ISS, board test sessions were performed to check the work capabilities; also the temperature measurement of critical BTLS-N points was done taking into account sunlight. Temperature measurement has shown that temperature corresponds to previously done calculations.

Next part of experiments was devoted to targeting of on-ground and on-board terminals. Targeting task in this experiment is complicated because of large size of ISS and low precision of its trajectory prediction. Mainly it affects the late time of ISS appearing in custom point.

Without knowing the precise location of BTLS-N terminal on ISS board, and it's coordinate system shift, it's hard to calculate the target coordinates (mount rotation angles) for on-board terminal using only information about ISS ephemeris.

For compensation of these errors during the start of targeting experiments a BTLS vision line scanning mode was implemented. Its purpose is to locate on-ground laser reference marks, after this BTLS should lock the target and start it’s auto-tracking.

On Fig. 5 red line shows the trajectory of BTLS mount vision line movement during scan and after on-ground reference mark lock. Blue line is a signal on on-ground detector camera.

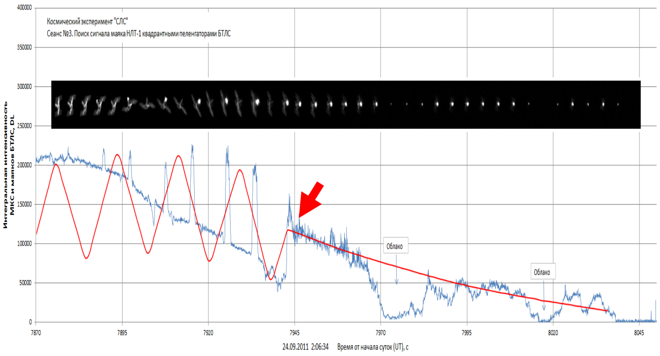

Fig. 5. Targeting system experimental results.

In first experimental sessions of on-ground terminal targeting and further ISS tracking by the moment of appearance of a signal from on-board laser reference marks on array detector was performed in zone of ISS pass through wide-field detector using the reflected of spacecraft sunlight. In further sessions targeting was performed in “blind” mode using ISS ephemeris and additional time error compensation with further on-board laser marks lock.

On Fig.5 results of mutual targeting of on-board and on-ground terminal are shown. You can see the trajectory of BTLS-N vision line movement (red line), video frames from NLT-1 array detector and signal brightness of ISS radiation on this detector (blue line).

You also can notice the trajectory of BTLS vision line scanning and splashes of NLT-1 detector signal brightness in moments of time when vision line passed through its field of view.

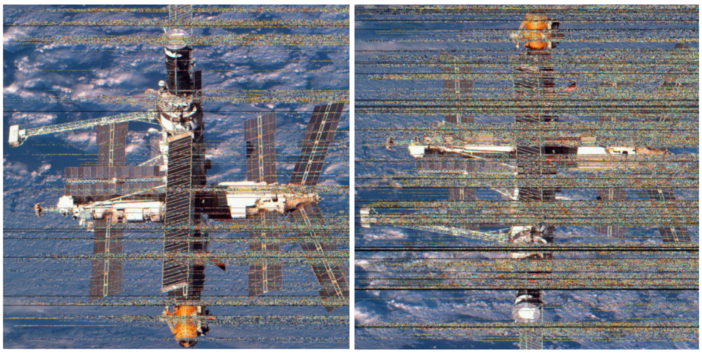

Fig. 6. Targeting system experimental results.

In the point of trajectory marked by red arrow the lock of on-ground reference mark by on-board terminal was achieved and tracking has begun. During this time vision line has passed twice through the clouds. Signal brightness of BTLS reference mark in these times was decreased to the level of background, but due to movement prediction, tracking was not lost in on-board and on-ground equipment. Tracking error is less than 1 arc second.

After successful system mutual targeting, 3 types of information transfer sessions were performed. Firstly test information (image of ISS, stored in board computer BTLS-N) was transferred with 125 Mbits/sec baud rate. On Fig.6 is shown how the quality of transfer changes during the session. It changes because of vision line decreasing from maximum altitude of 30 to 13° above the horizon. On low angles the influence of atmospheric distortion on data transfer quality.

Also test information on 622 Mbit/sec baud rate was transferred during this part of experiment.

Also scientific information transfer from ISS board BTLS-V was performed on 125 Mbit/sec baud rate. The amount of errors during transfer is from $3x10^{-8}$ up to 10^{-6}. Atmosphere influence on transferred information quality was not research in this part of work.