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Communication channel for small-size spacecraft on the base of the GLOBALSTAR satellite communication system

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Abstract. The usage of the available global general purpose satellite communication systems for control of small-size spacecraft is considered a peromising and low-cost direction. The most suitable system to fulfill this task is the GLOBALSTAR. For the first time a communication through this system was carried out by the nanosatellite TNS-0 № 1 in 2005.

The article shows the results of the comparative analysis of the experimental data received from TNS-0 № 1 and computer modeling of the mission conditions using the "Radio coverage zone of TNS-0" software. Favourable communication conditions in which the technology for small-size spacecraft control with use of the GLOBALSTAR system is very effective, low-cost and operationally convenient, as well as realized both in stationary and mobile variants, are defined. It is determined that the area of space where communication can be possible is a so called "cone of communication" in which the small-size spacecraft, a GLOBALSTAR spacecraft and a ground gateway should be simultaneously.

The article describes specific causes of lack of communication. Practical recommendations on increasing the amount and duration of communication sessions are given. A new way for communication channel organization using GLOBALSTAR satellite communication systems is proposed. The results of the ground tests are presented.

Keywords: nanosatellite, small-size spacecraft, GLOBALSTAR, space communication system, zone of radio visibility.

The use of satellite communication systems (SCS) for commercial applications to control small-sized spacecraft (SSS) is currently a promising and low-cost direction.

Among the existing SCS (INMARSAT, IRIDIUM, Orbcomm, Thuraya, Globalstar) the most suitable for the task is the Globalstar System.

The high altitude of the satellites' orbit (H = 1400 km) provides a broad coverage area for the SSS. The weight of the user equipment (a satellite modem and an antenna) does not exceed a few hundred grams, therefore it can be used in the SSS. The system is certified in Russia.

For the first time the CCC Globalstar channel was implemented on the nanosatellite TNS-0 №1 (Fig. 1). This is one of the first Russian nanosatellites. It is made in JCS RSS and on March 25, 2005 has been launched "manually" from the ISS. Active work with the satellite took place till July 6, 2005, when it completely consumed the energy supply of the onboard battery.

One of the main objectives of launching the TNS-0 №1 nanosatellite was to test the possibility of communication sessions between the satellite and the terrestrial MCC using SSS Globalstar, as well as network monitoring to determine the SSS control capabilities through the system.

Fig. 1 Nanosatellite TNS-0 №1

The scheme of information exchange between SSS and MCC using the Globalstar system is shown in Fig. 2

For successful communication sessions with the MCC, the SSS and the ground gateway (GG) must simultaneously be in the radio visibility zone (RVZ) of the Globalstar spacecraft (GS SC). A "cone of communication" is the space where communication is possible, it has the following parameters:

- the vertex is located in the center of mass of the GS SC;

- the semi-apex angle $\boldsymbol{\alpha}_{max}$ is determined by the radiation pattern of the antenna of the GS SC.

Figure 3 shows a diagram of the combined radio visibility zone of SSS - GS SC - GG.

The design of nanosatellite TNS-0 №1 is shown in Figure 4

Communication and management TNS-0 №1 was carried out through GSP 1620 modem of the Globalstar system (Fig. 5). The modem was turned on automatically for 10 min each hour of flight. If it was possible to establish a link, an exchange of information with the ground mission control center was carried out.

At the end of the LCI analysis of the results. During the analysis, the following data were used:

– ***MCC data on the conducted communication sessions;***

– ***catalog numbers of the active satellites in the Globalstar orbital constellation.*** The data were obtained experimentally. It was established, that during the FDT of the TNS-0 №1 of the nominal 48 GS SC only 36 were active, which, of course, reflected in the number of successful communication sessions;

– ***Globalstar data on registrations of the TNS-0 №1 in the network.*** Monitoring of the registrations was performed by the Globalstar service provider in Russia, GLOBALTEL, in accordance with the agreement that had been reached earlier;

– the orbital data (TLE) of the NORAD aerospace control system on SSS and active GS satellites. Data archives are publicly available on the Internet site https: space-track.org.

– coordinates of the terrestrial gateways and their coverage area. The data obtained from the technical description of the SCS Globalstar.

Computer simulation of the conditions of TNS-0 №1 flight was conducted using the RVZ TNS-0 №1 software (Fig. 6).

The communication sessions calculation results are shown in Fig.7.

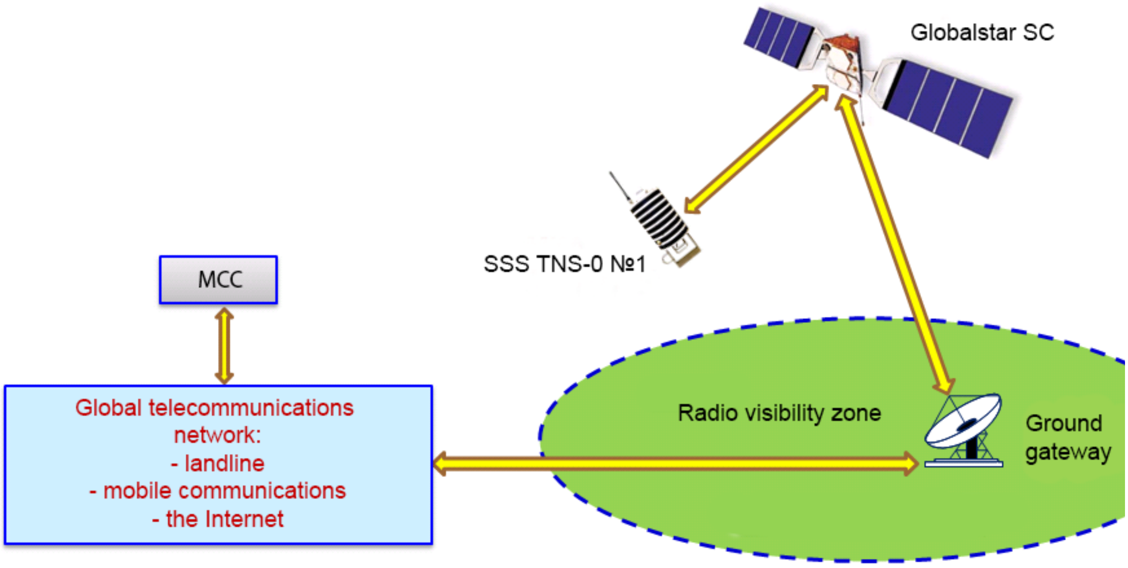

Fig. 2 Scheme of information exchange between SSS and MCC

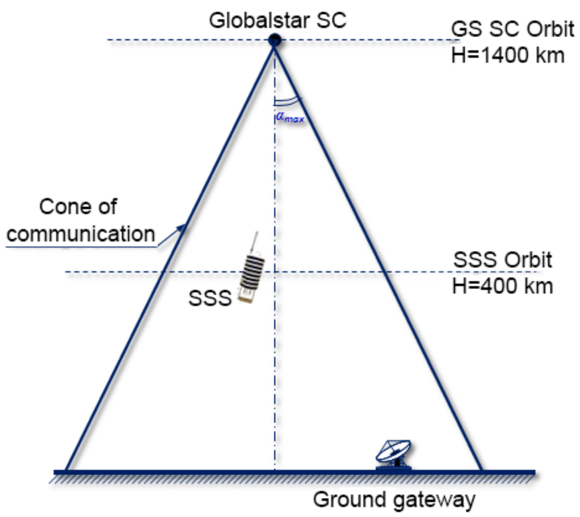

Fig. 3 scheme of the combined RVZ of SSS - GS SC - GG.

Fig. 4 The appearance of the nanosatellite without cover

The results of the FDT post-flight data analysis of TNS-0 №1:

1. The flight design tests (FDT) of the TNS-0 №1 nanosatellite were successful. Active work of the satellite continued 68 days 20 hours 31 minutes (from 09:39 Moscow time 28.03.2005 till 06:10 Moscow time 05.06.2005). During this time, the TNC-0 №1 made 1086 circuits. The satelliet conducted 22 communication sessions, including 11 sessions with the MCC-1 (stationary, Globalstar communication system) and 12 sessions with the MCC-2 (mobile, "MTS" communication system). During the session 8 the link was established alternately with MCC-1 and MCC-2. The total duration of sessions was 34 minutes 49 seconds. The TNS-0 received 561397 bytes (8731 frames), and transmitted 70280 bytes (8770 frames) of information by the means of the MCC. The received signal strength indicators (RSSI) were obtained during the tests.

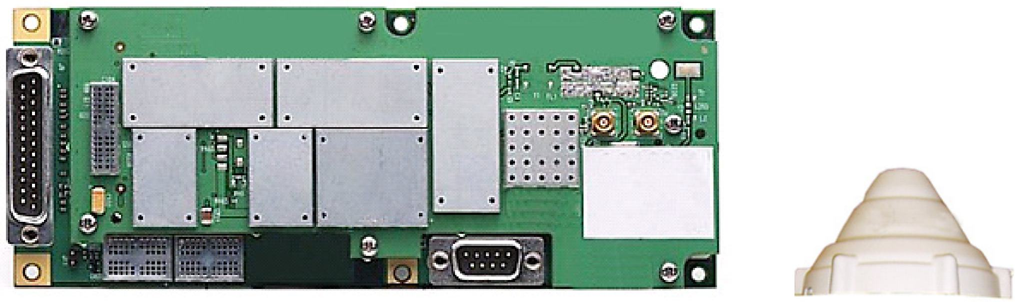

Fig. 5 GSP 1620 modem with the QUALCOMM ANTENNA

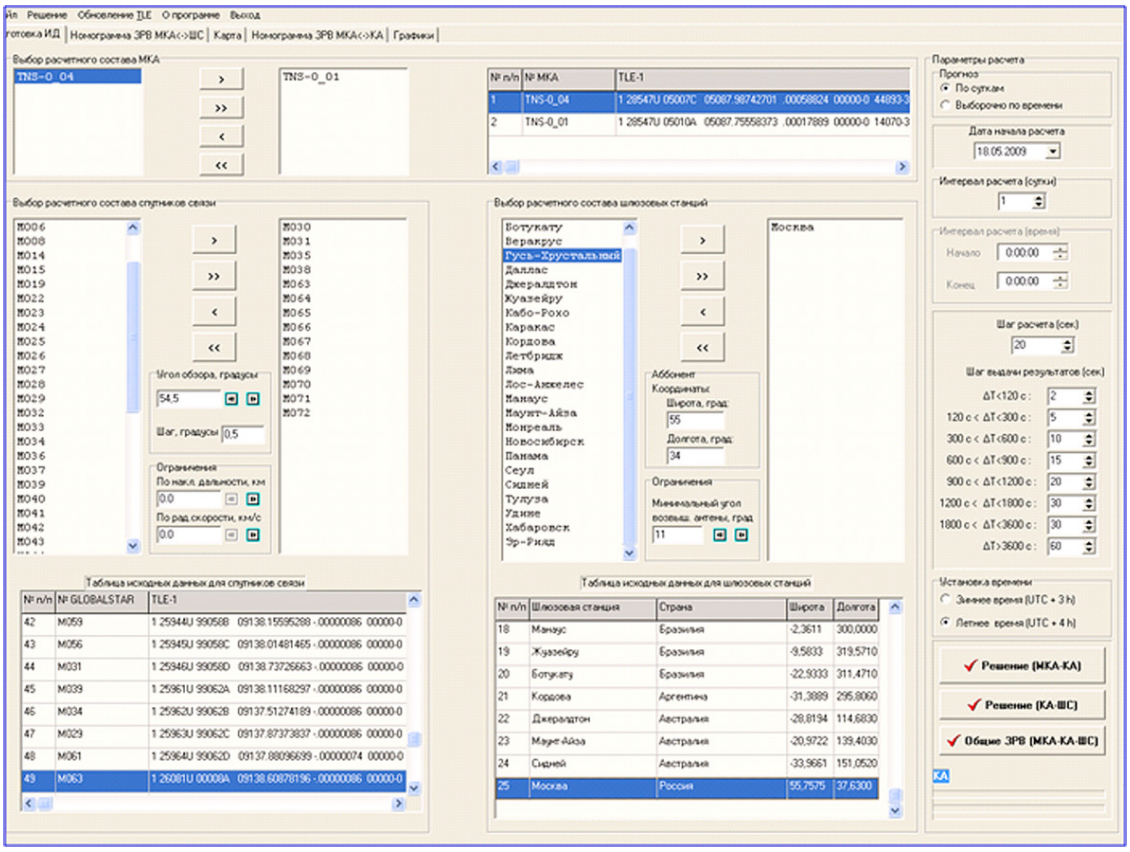

Fig. 6 Central window of the RVZ TNS-0 №1 software

2. Favorable communication conditions under which the SSS control technology using the Globalstar network is highly effective, low-cost and user-friendly, and operationally realizable both in stationary and mobile versions were identified. At the same time, the conditions associated with unstable orientation and stabilization of the spacecraft, the mismatch between the current location of the spacecraft and the service areas of the Globalstar system when such communication is unreliable and it should not be used were identified.

Monitoring of the conditions of communication through the Globalstar system showed that:

- 50% of the activations of the Globalstar modem occured outside the service zones of the regional operators;
- during 12% of the activations roaming was unavailable;
- during 14% of the activations in the link between the TNS-0 №1 and GLOBALSTAR spacecraft was unstable (communication disruption);
- during 24% of the activations the quality of the communication channel was sufficient for the data exchange with the MCC.

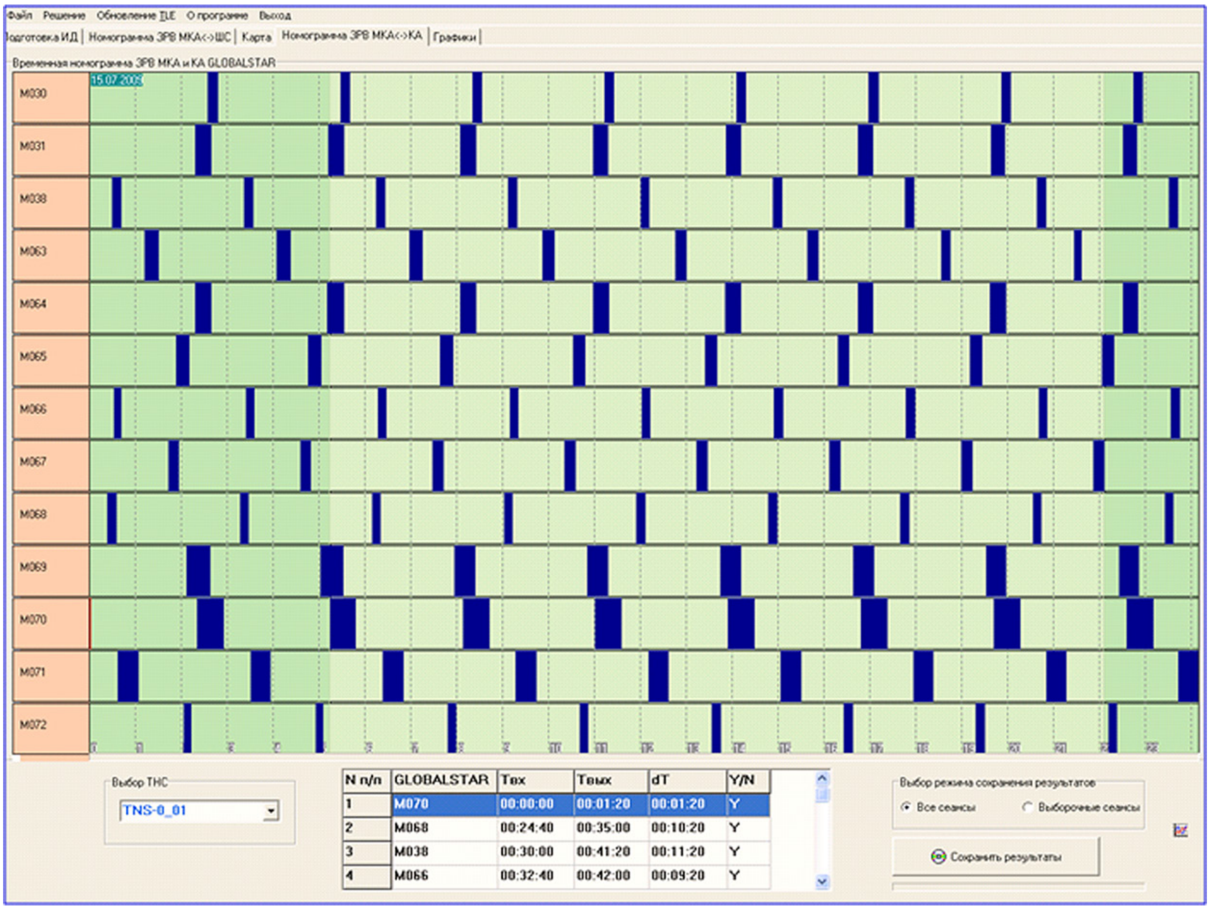

Fig.7 The communication sessions calculation results obtained from the RVZ TNS-0 №1 software

3. the tests of the “RVZ TNS-0” software proved the choice of algorithms for calculation of radio sessions between the MCC and the SSS to be correct. Most of the experimental data received during the monitoring of the GLOBALSTAR network corresponds to the calculations with a sufficiently high accuracy. However, some data does not correspond to the calculations. In particular, RSSI outside the RVZ is detected. Perhaps this effect is due to re-reflections of radio signal in the atmosphere. For a more detailed study of the causes of some data disagreement with the calculation, work needs to continue, including the new space experiment with the use of nano-satellite TNS-0 №2.

Space experiments demonstrated the possibility of using the Globalstar SCS for the SSS Control. However, the number of successful sessions with the MCC (24%) is insufficient. In future devices, measures to improve it must be taken.

Methods of increasing the number and duration of the communication sessions with MCC in the Globalstar network.

1. ***A preliminary calculation of communication sessions.***

The method is as follows. The MCC makes a preliminary calculation of the combined RVZ of the SSS, the active GS SC and ground-based gateways. Such a calculation can be performed using the software package “RVZ TNS-0” on the basis of the current orbital data (TLE) of the spacecraft. Then the long-term schedule of activations (for 3-5 days) is transmitted to the SSS.

Disadvantages:

- error of calculation of sessions is less than 30 seconds. Such accuracy can be considered acceptable for building mission scenarios with communication sessions in the “broad” service areas with the time span of 5-10 min. However, for “narrow” zones (≤ 3 min.) such accuracy is insufficient.

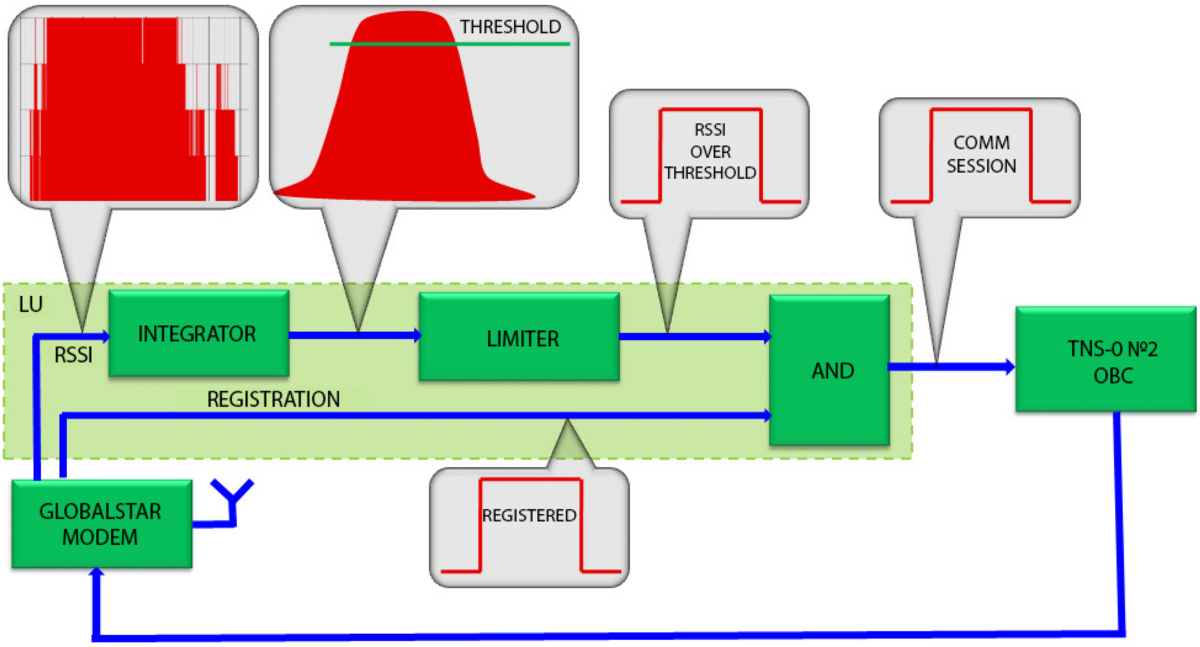

Fig. 8 Schematic diagram of the autonomous operation mode of the Globalstar modem

- the need for regularly updated orbital data and calculations of communications sessions with the subsequent transfer of the data to the satellite.

2. Autonomous activation of the Globalstar modem (patent number 2520352 from 23.08.2012)

The method of autonomous activation of the SSS modem based on analysis of service information from the Globalstar network is deprived of the shortcomings of the first method. The method is as follows.

The general stream of data coming aboard the SSS contains service information (SI), that serves to provide the performance of the Globalstar system. The specially developed software installed on board the satellite, separates the SI signals from the general stream of information. As a result of the subsequent processing of the SI in the logical unit (LU) by pre-worked out algorithms, commands are formed and sent to the satellite computer, which controls the Globalstar modem. Therefore, the start time and duration of sessions is determined by the on-board LU in the automatic mode and does not depend on instructions from the MCC. Calculating RVZ is not required. In this mode, during the communication sessions, in addition to the basic information from the SSS, the SI of the Globalstar network is transmitted to the MCC. The SI will increase the accuracy of the post-flight processing of the SSS FDT results.

Fig. 9 TNS-0 №2 simulator

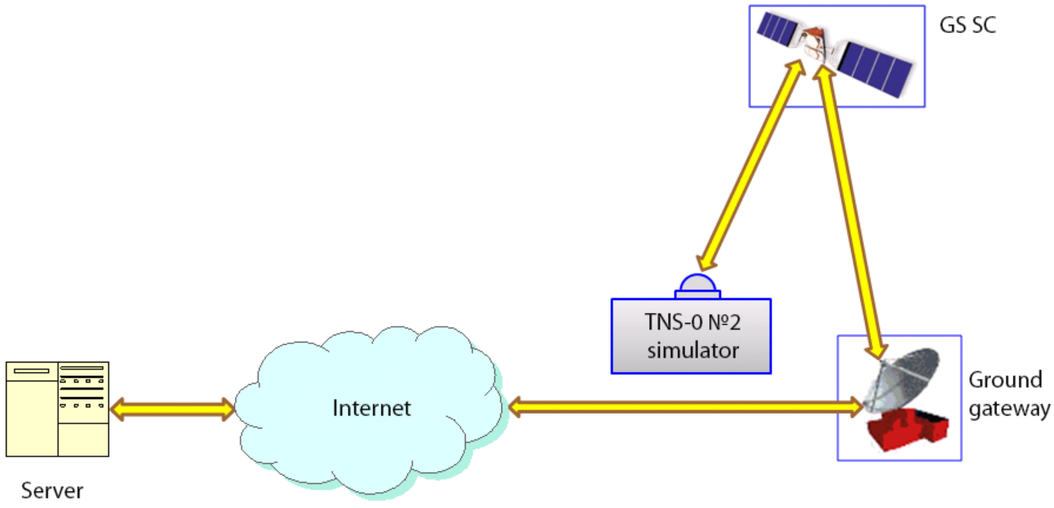

Fig. 10 Scheme of data exchange in the Globalstar network between the TNS-0 №2 simulator and an Internet server in packet mode

The presence of a stable link to the Globalstar system is determined by the following SI signals:

– "RSSI" signal. This is a signal indicative of the quality of the communication channel "Subscriber – Globalstar satellites – terrestrial gateway". It is produced by the modem based on the analysis of the incoming signals from the Globalstar network. The amplitude of the RSSI signal to ensure a stable link must be at least 3 units on the signal strength scale;

– "Registration" signal. Is fed to the modem after the registration process in the Globalstar network. Simultaneously with the "Registration" signal, the modem receives the number of the GG through which it should establish a link.

The user (single-port) mode of the modem does not support the separation of the SI signals. To separate the SI signal, the two-port modem configuration is used.

The schematic diagram of the Globalstar modem operation in the autonomous mode is shown in Fig.8.

The signals from the "Control port" modem are fed to the logic unit (LU), that consists of an integrator, a limiting controller and an "AND" logic circuit. All the constituents of the LU are implemented in software.

The system operates as follows. During the flight of the SSS, the on-board Globalstar modem operates in standby mode with its receiver turned off. When the satellite enters the RVZ, the "Control port" of the modem receives the RSSI signal. Next the RSSI is fed to the integrator. As a rule, the beginning (and the end) of the communication session is characterized by rapid changes in the RSSI level, resulting in unstable communication. To eliminate this phenomenon, an integrating link is included in the scheme of the automatic modem control. The amplitude of the signal at the output of the integrator is equal to the arithmetic mean of the ten current RSSI level readings.

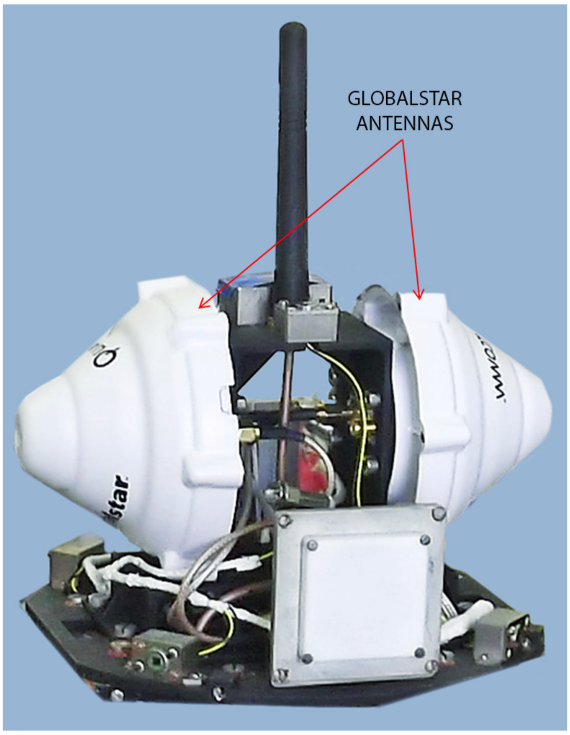

Fig. 11 TNS-0 №2 with an additional antenna

Then the limiter compares the current value of the signal with a predetermined threshold value. When the signal level exceeds the threshold, the limiter sends a logical one to one of the inputs of the "AND" circuit. If the satellite is registered in the network, the modem sends a logical one to the other input of the logical circuit. In this case, the output of the logical "AND" circuit also generates a logical one. Then, a command in the form of positive voltage is sent to the on-board computer for it to activate the operating mode of the modem. A communication session between the SSS and the MCC takes place.

When the satellite leaves the RVZ, the RSSI level drops to zero. The "And" logical circuit generates a logical zero. The on-board computer terminates the session and puts the modem in standby mode.

Experimental testing of the automatic operation mode of the modem in the Globalstar - Internet network was carried out in the ground conditions on a TNS-0 №2 simulator. The appearance of the TNS-0 №2 simulator is shown in Fig.9.

In the course of the experiment eleven communication sessions with a remote Internet server with an average duration of 6 minutes were conducted. This time is sufficient for transmitting a test message from the TNS-0 №2 simulator to an Internet server and receiving a response test message (~ 1 min.).

All the test messages were fully transmitted and received, without errors and data loss. The average speed of data transfer is 7 kbit/s. This value is very close to the maximum possible data rate in the GLOBALSTAR network, which is equal to 7.2 kbit/s.

3. Using a packet data transfer mode.

The Globalstar network supports two data transmission modes: the asynchronous mode, when the connection is established via the PSTN and GSM terrestrial networks; and the packet mode, that uses the Internet. Connection with terrestrial networks is carried out using different servers. Obviously, the time of connection establishment will be different for different modes. During the ground experiment on the TNS-0 №2 simulator, the time of connection establishment with the subscriber was measured. The average time taken to establish a connection is T = 34s in the asynchronous mode, and T = 5s in the packet mode. A significant reduction in the time of the connection establishment (≈ 7 times) allows to increase the length of communication sessions. This is especially important for the "narrow" RVZs, lasting less than three minutes.

For the scheme of information exchange in the Globalstar network between the TNS-0 №2 simulator and an Internet server in packet mode, refer to Fig.10.

The results of this experiment show that it is advisable to use the packet mode in the future launches of the SSS. An additional advantage of this mode is that in case the MCC is currently unavailable for communication, the data is stored on an Internet server of the Globalstar provider and can be received by the MCC operator when the communication is restored.

During the flight, TNS-0 №1 used the asynchronous mode, which had a negative impact on the number and duration of sessions.

Fig. 12 VHF modem Roger KD 9600.

Fig. 13 Antenna with circular polarization.

4. Set-up of an additional transceiver Globalstar antenna.

A secondary antenna (diametrically opposed to the primary one) and two couplers will increase the total radiation pattern of antenna feeder device (AFD) approximately twofold that will lead to a substantial increase in the number of communication sessions. Fig. 11 shows a photo of the TNS-0 №2 antenna unit with an additional antenna.

5. Introduction of a backup VHF communication channel.

The Roger KD 9600 modem has the most suitable technical and mass-dimensional parameters. Photos of the modem are shown in Fig.12.

To eliminate the Faraday effect, associated with the change of the polarization plane of the received signal, the terrestrial VHF reception station should employ an antenna with circular polarization (Fig.13).

Conclusions.

1. From the analysis of data obtained during the FDT of TNS-0 №1, it follows that the information field of SCS Globalstar is not global and continuous. The structure of the field depends on the characteristics of the GS spacecraft orbits and the number of active spacecraft in the constellation.

2. FDT of TNS-0 confirmed the possibility of using a communication channel on the basis of Globalstar for the SSS control.

3. To increase the number and duration of sessions is recommended to use a five-item set of design solutions designed after the analysis of data obtained during the flight tests of THC-0 №1 and presented in the article. Experimental ground testing showed their high efficiency. A final check of the new design solutions must perform in a real space flight. Such tests are scheduled to take place on the next nanosatellite, TNS-0 №2.

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