ISSN 0010-9525, Cosmic Research, 2015, Vol. 53, No. 3, pp. 186–192. © Pleiades Publishing, Ltd., 2015.
Original Russian Text © M.S. Burgin, P.A. Voytsik, A.M. Kutkin, M.M. Lisakov, E.N. Mironova, K.V. Sokolovsky, E.N. Fadeev, 2015, published in Kosmicheskie Issledovaniya, 2015, Vol. 53, No. 3, pp. 199–206.

Monitoring and Control of Onboard Scientific Equipment of the Space Radio Telescope

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Received December 16, 2013

Abstract—This paper outlines the methods used at the ASC LPI for generating instruction sequences that control operation modes of the onboard scientific equipment and describes the means for timely receipt of information about the current state of the onboard equipment, thus making it possible to quickly assess the adequacy of the selected modes for the solution of scientific problems and respond to emergency situations. The main points of interaction with other subsystems and their controls are briefly described.

DOI: 10.1134/S0010952515030041

INTRODUCTION

The main objective of the ground segment of the control system of the onboard scientific equipment (OSE) of the space radio telescope (SRT) is the preparation and transmission of sequences of instructions to the orbital observatory RadioAstron, in order to optimally control it from the point of view of the scientific program of the ground–space interferometer described in [1]. The effective functioning of the interferometer is impossible without the correct operation of a large number of very heterogeneous subsystems, which are either its integral part (space radio telescope, scientific tracking stations, and ground radio telescopes) or are parts of the system providing the interferometer with the necessary material and information resources (basic space platform Navigator, ground-based infrastructure that provides control of the orbital observatory and delivery of data transmitted by it to end users, the means of determining the parameters of the orbit, etc.). These subsystems are controlled by a large number of organizations, including the ASC LPI, NPO Lavochkin (NPOL), IKI, numerous ground-based radio astronomy observatories, etc.

SCHEDULING OF SRT SESSIONS

From the point of view of the scientific program, the basic block of scheduling is the session of observations in the Very Long Baseline Interferometry (VLBI) mode. In most cases, during the VLBI session the antenna of the space radio telescope is constantly pointing at the examined object, which is also observed from ground VLBI stations. The antenna of the highly informative communication channel (VIRK) [2], which provides the broadband interferometric signal transmission from the spacecraft, is pointing at one of the ground tracking stations (STS) that receive and record the transferred data.

In addition to VLBI sessions, the SRT equipment is used in some other types of sessions. Of these, so-called “adjustment sessions” designed to determine SRT gain pattern and control the system of satellite orientation are the most important for the implementation of the scientific program and most frequently carried out. Ground-based observatories are not involved in these sessions, and with the help of the SRT the isolated point sufficiently bright object is observed. During the observations the satellite orientation is changed by a predetermined program so as to be able to measure the change in the received signal power observed at the displacement of the object relative to the optical axis of the SRT antenna. The measurement results are recorded to the onboard memory and then transmitted to the Earth via the base platform communication system.

In order to eliminate possible interference from satellite electronics, communications between the base platform and the Earth are minimized when SRT receivers are running. Data transmission from the satellite to the Earth during the VLBI sessions occurs only through VIRK, and base platform transmitters are switched off. All control instructions are recorded by the onboard equipment in advance to the memory of the onboard control system for communication sessions, so-called *control sessions*, organized specifically for this purpose. From the point of view of maximizing the time available for astronomical observations, it is desirable to carry out as seldom as possible control sessions and to set programs for the greatest possible number of VLBI sessions in each flight mission. However, the final amount of memory of the onboard computer system and other factors impose certain limitations on the total number of SRT control instructions transmitted in one control session and as for the interval between two successive control sessions. As a general rule, this interval ranges from a few hours to several days and during that time from 1 to 20 VLBI sessions are made every 30–60 minutes.

The first stage of the preparation of observations on the ground–space interferometer is a compilation of the best month session schedule compatible with all the limitations imposed on the work of the ground–space interferometer. In this case, the degree of satisfaction of requests from scientific groups is the optimized parameters. Limitations are caused by natural (visibility of sources from the satellite and ground VLBI stations, visibility of the satellite from tracking stations), technical (limitations on the duration of VLBI sessions using the SRT and intervals between them, the need to allocate time for control sessions, etc.), and organizational (if ground VLBI stations are used by other programs) reasons.

There are two approaches to the use of the ground–space interferometer for the solution of scientific problems: a review of the petals and imaging. The lobe review involves measurement of the amplitude response of the interferometer (the interference lobe) on several space–ground bases for the subsequent comparison with a simple parametric model. This model can specify spatial (when extragalactic sources in the continuum are observed) and spectral–spatial (in observations of masers) brightness distribution, or statistical characteristics describing the scattering of radiation in the interstellar medium (in observations of pulsars). The processing of observations makes it possible to obtain model parameters and, thus, information about the physical properties of the objects. Observations in the review of lobes usually consist of several separate sessions. The duration of each session is determined by the need to obtain several independent measurements (each of which is limited to possible time of the coherent signal accumulation, which is about 10 minutes at centimeter wavelengths) and is usually of the order of one hour. The interval between sessions included in the review is determined by the time required for a significant change in the base due to the satellite motion. In survey observations at least one large ground-based telescope should be used to obtain a response on the ground and space base and one telescope with a smaller diameter to measure the amplitude of the response on the Earth-to-Earth basis and to correct the operation of a large telescope. Advantages of the lobe review include small requirements for observation time and number of involved ground-based telescopes. There are also no fundamental limitations on the size of projection of the ground–space base. The main limitation of the method is that its results are model-dependent, and their accuracy depends on how adequately the used model describes the object under study.

Imaging requires a large number of ground-based telescopes observing together with the SRT for a long time with short breaks for cooling of the space telescope and calibration of ground-based telescopes. The results of measuring the amplitude and phase of the correlated signal on a large number of different databases make it possible to restore the image of the radio source using the inverse Fourier transform of the measured signal with the help of complex algorithms CLEAN and self-calibration (the so-called *hybrid mapping*). This method of observation makes it possible to obtain much more information about the structure of the radio source than observations in browse mode. However, it has limitations associated with the necessity to sufficiently uniformly fill the investigated range of bases with measurements. In practice, it means that for a successful recovery of the image the maximal ground–space base should not be more than a few times more than the maximal land base. This condition imposes a limitation on the achievable angular resolution of the interferometer and requires observations at the time when the satellite is near perigee.

The initial data for scheduling are applications from scientific groups for observations that describe problems sand used approaches. When scheduling observations, firstly, dates of imaging experiments are determined, because they are rigidly associated in terms of time with the interval near perigee passage and require a large number of ground-based telescopes. Since possibilities of many telescopes for joint observations with the SRT are limited, the organization of such experiments requires the coordination of the observation time with ground-based observatories 6–12 months in advance. Such long-term scheduling creates difficulties associated with the inability to predict the observation time for the SRT because of the limited accuracy of the long-term orbit prediction. When scheduling for the year ahead, real SRT observations can be shifted with respect to the planned ones by a few tens of minutes. The negative consequences of such a shift are partially mitigated by the long duration of mapping experiments, which usually take more than 10 hours. Short observations under lobe review, for which the prediction accuracy of the observation period of a few minutes is critical, are scheduled for 1–4 months. At the same time, review sessions are scheduled in intervals unoccupied by observations in order to construct the image. The calculation of the visibility of radio sources by space and ground-based telescopes is carried out by software Fakerat [3] and SCHED (http://www.aoc.nrao.edu/software/sched/index.html). These programs can be used in an interactive mode, where the experimental conditions are defined directly by the user, and in batch mode, where the initial data generation and the analysis of the results are performed automatically by the control instruction procedure autofake.sh implemented in bash. The batch mode makes it possible to conduct mass testing of visibility conditions for a large number of radio sources and prolonged period of time that is necessary in the scheduling of observations in the lobe review mode. Control procedures are written in bash and are available on request from one of the authors (kirx@scan.sai.msu.ru). In the preparation of a series of observations of active galactic nuclei held in lobe review mode, a computer program (http://adsabs.harvard.edu/abs/2013arXiv1303.5451S) was developed in order to automate the scheduling of sessions. As initial data, the program uses a list of sources that are of interest in terms of observation, the information about their visibility for space and ground-based telescopes provided by the procedure autofake.sh, the history of previous observations, the source priority information (higher priority is assigned to sources for which the observation possibility is rare), and a list of intervals that cannot be used for observations because they are used by other research programs, block control sessions, or because the device entered the Earth's shadow.

The program distributes available observational time between the studied sources and ensures the duration of the intervals between sessions sufficient to provide acceptable thermal mode of the satellite. When selecting sources for the monitoring, the preference is given to those seen by the largest number of ground-based telescopes (in order to increase the likelihood that there will be enough telescopes ready to carry out observations at a given time interval) and to those that can be observed at very different projections of the base and position angles of the base for one or more close orbits. Under otherwise equal conditions, the preference is given to the sources, the direction to which with the direction to the Sun makes angles in the range of 90°–110°, the most favorable in terms of the satellite thermal mode. The automation of scheduling for observations makes it possible to use all the available observing time with maximum efficiency.

After receiving applications for observations within a month from all research groups the combined request is sent to NPOL for the ballistic and thermal testing. At the same time, requests for ground-based telescopes are sent. Their responses make it possible to establish which of the possible sessions have a sufficient support from ground-based telescopes and approve the final schedule for the month. The approved program of observations becomes the basis for the tasks for the space and ground-based telescopes. The control of ground-based telescopes, as well as data recording from the space telescope to the STS in Pushchino and Green Bank, is carried out using vex-files created by the SCHED software. These files have a standard format that is widely used in ground-based VLBI observations and contain full details of the experiment including frequency settings, recording time, and coordinates of radio sources and telescopes that observe them. The generation controlling *vex*-files using SCHED based on the approved schedule, their storing on the primary and backup FTP servers, and the notification of VLBI stations that the schedule is ready are carried out by a set of programs that are also implemented on bash.

GENERATION OF FLIGHT TASKS

The sequence of instructions that are written during the control session into the memory of the onboard computer complex is called the flight task (FT) and is the basic block of data exchange between ground and spaceborne parts of the satellite control system. In normal operation mode during the FT execution no additional instructions come on board. In the standard representation used to in the transfer data from the ASC LPI to NPOL, the flight mission is a text file that contains blocks of the following types

1. OSE SRT control instructions.

2. Plasma-F control instructions. This part of the FT is prepared at the IKI RAN and is combined with other parts of the task prepared at the ASC LPI before the transmission of the FT to NPOL.

3. Pseudo comments controlling the subsystem for the receiving of telemetry data.

4. Comments.

The scheduled execution time is specified for each control instruction. Blocks of type 3 and 4 do not directly affect the content of the program transmitted to the satellite. The use of the information contained in blocks of type 3 is described in the following sections of this paper. By September 2013, more than 500 flight missions were created at the ASC LPI. The experience of the first months of operation, when it was necessary to generate 2 to 10 FTs per month each containing 1–2 VLBI sessions, showed that the complexity and the probability of observation time losses because the operational errors in manual FT preparation mode are too high, and it is necessary to automate the preparation of flight tasks to the maximum extent possible. The first automatically created FT files appeared in August 2012, and further the preparation of the FT became almost completely automated. By the moment, the number of automatically created FTs has already exceeded the number of the ones prepared manually.

In FT development two specialized programs are used: a program for FT automatic generation and a program for FT correctness control. The need to create two programs, with somewhat overlapping functions, is caused by the following reasons. First in some cases, in the last phases of preparation automatically generated FT is subjected to some manual modifications. In particular, it occurs in the cases where the previously not tested OSE modes are considered. The subsequent validation can detect errors that could be made during manual revision. Second because the consequences of errors in the FT can be quite serious (completely or partially lost observations), it is desirable to minimize the impact of possible errors in the automatic FT generation. Because the generation program and the control program were created and run completely independently from each other (written by different authors in different programming languages and under different operating systems), the probability that the error in an automatically created FT will not be detected when validating is vanishingly small.

The program for automatic FT generation is implemented in Perl v. 5.14 under Linux. Input data for the program is a schedule of the SRT operation that contains information about observations, control sessions, adjustments, etc. Monthly schedule includes descriptors of all the observations planned for the corresponding time interval. Each descriptor contains the following information used to generate the FT instructions: time of the beginning and the end of the observation, used receivers, the formator mode, the VIRK power, the name of the tracking station and its operation time. In addition, the descriptor contains the following information, which does not affect the sequence of generated instructions but is used in comments: the experiment code, list of ground-based telescopes involved in the experiment, the name and coordinates of the observed object. Hash arrays are used as an internal representation of the original schedule and generated flight missions. The time (of the beginning of observations according to the schedule or issuing of instructions in the FT) in the POSIX format is used as indices of these arrays i.e. a number of seconds elapsed since January 1, 1970, 00:00 UTC, and the attributes of a session (for schedules) or issued instructions (for FT) are values. When scheduling ground-based VLBI observations, the so-called *experiment code* is used for their identification. However, it proved to be impossible to use code for the identification of SRT observation sessions, because in some cases there is no unambiguous correspondence between the ground observation code and the SRT session. For communication with the subsystem of scheduling of ground observations, the experiment code is stored in FT comments as one of the attributes of the session.

In the first phase of the program operation, the monthly schedule is translated into an internal representation and is divided into parts by limited subsequent control sessions. From each such part the main module of the program creates a separate FT. All SRT control instructions including receivers, setting of the operation mode or rearrangement of formator keys, setting of the heterodyne frequency, system calibration, changing of settings of attenuators, etc., refer to one of the logic blocks. Instructions that belong to the same block control the same device, and the flight task is made so that among the instructions belonging to one of the blocks there were no instructions from the others. There are two types of instruction blocks. For the so-called *fixed* blocks the execution start is rigidly associated with a particular event specified in the input data of the program. Fixed blocks include calibration blocks (calibrations should be carried out strictly before the observation and after their completion), VIRK transmitter power control blocks (the transmitter power can be changed either before the reception of data by the ground-based tracking station or after the transmission is completed), on/off instructions for receivers that need to ensure that receivers are off during the control session. The remaining blocks are classified as relocatable. The starting time of fixed blocks is determined based on the schedule of observations, is recorded in the associative array, is used as an internal representation of the FT, and is not changed later. Next, the duration is calculated for each block based on the fact that the time between the issuing of successive instructions is 5 s and given the fact that most of the instructions are repeated in order to increase reliability. Once the duration of all the blocks is determined, and fixed blocks are inserted in the FT, relocatable blocks are sequentially inserted in the associative array. At the same time, the beginning of execution of each next block is selected so as to ensure that there is no overlap with already inserted ones. When all blocks are inserted, the FT is converted into the external representation and is stored to the output file.

The program for the FT verification is implemented in MATLAB and runs under Windows. The program reads the flight mission file and checks the syntactic correctness of instructions. Next, it is checked if the sequence of the issuance of instructions and the duration of intervals between the instructions satisfy given limitations. After that the operation logic of the onboard scientific equipment is simulated, and the dependence of its state on the time that corresponds to the verified flight mission is determined. The results are displayed in graphical form optimized for visual inspection by experts of the control group.

COMPOSITION AND CHANNELS OF OSE STATUS TRANSMISSION

The OSE status information processed at the ASC LPI contains three data streams that differ in their purpose, origin, and method of delivery and processing.

The sampled wideband video signal generated by the shaper [4] is used as input data during the correlation processing. Because of the high information content (~128 Mb/s), this stream can be transmitted to the Earth only via VIRK. The provision of adequate statistical characteristics of the signal, in fact, is one of the main objectives of the experiment control system. The description of the methods of its processing is given in [5]. It is not considered in this paper.

Included in the OSE measured by TMS-P (standard SC telemetry system) parameters of devices (hereinafter, for brevity, TMS parameters). TMS parameter values can be transmitted to Earth either via standard SC means (in real time or with prerecording to the onboard memory) or from the TMS-P to the shaper and further to the Earth simultaneously with the video signal in headers of VIRK frames. When transmitting via standard means, primary data processing is carried out at NPOL and then through IKI results are transferred to the ASC. When transmitting through VIRK, data are received on one of the scientific tracking stations and then are transferred to the ASC and NPOL.

A small number of OSE parameters (hereinafter referred to as *directly telemetered* or DT-parameters) can be written by the shaper directly in VIRK frame headers without the use of TMS-P, and after the transfer of the Earth they are delivered from the STS to the ASC. The most important of DT-parameters are called *output codes* that characterize the statistical properties of the video signal and, thus, the whole OSE operation.

In this paper, the methods are described that are used for the transfer of OSE parameters in the ASC (the parameters are received at scientific tracking stations as part of the VIRK frame headers) and their primary processing algorithms.

Data from the demodulator output received by the STS are fed to the telemetry decoder [6], which allocates values of telemetered parameters from VIRK frame headers and adds the service information generated at the STS to them. For each VIRK header the service information includes the time of reception of the corresponding frame by the decoder and the number of parity errors detected in the frame. For each frame, the decoder generates a separate text string that is written to a file on the hard drive and can be simultaneously transmitted over the network to the server of the telemetry processing. In normal mode when writing to disk one file corresponds to each VIRK data receiving session. When transferring via network, a UDP datagram corresponds to each record. Files recorded to the hard disk are subsequently transmitted via FTP to the storage server of the Scientific Data Processing Center.

PLANNING AND IMPLEMENTATION OF RECEPTION OF TELEMETRY DATA

The telemetry processing system is designed to convert data received from the decoder of the STS data to the form that greatly simplifies further analysis and to provide end-user access to the processing results. The processing results are the main source of information about the state of the equipment, and in case of emergency situations decisions are made about these or other changes in the flight mission based on the analysis of these results. In this regard, the system should make it possible to analyze the results and prepare modified FMs before the next control session if possible. The system includes a primary processing subsystem TMKRT that consists of a set of programs running on the servers of the centralized processing of telemetry and a number of specialized secondary processing subsystems designed for the analysis and visualization of data relating to individual OSE devices or groups of telemetered parameters. Further, the primary processing subsystem and the means used for its connection with the programs of secondary processing are described. The TMKRT subsystem performs the following basic operations

1. Scheduling of sessions of the reception of data transmitted over the network by the STS decoder.

2. The preparation and completion of reception sessions.

3. The reception and storing of source data received over the network.

4. Demultiplexing of nested substreams included in the total stream of data from the STS.

5. The allocation of TMS-P frames and the formation of a file in the TMI format.

6. The averaging of power codes and the formation of the file in the TPA format.

7. The copying of files with source information and files with processing results obtained via network to the server of the Scientific Data Processing Center of the ASC.

8. The express analysis of processing results and, in the case of anomalies, sending of messages with a warning diagnostics.

If necessary, the execution of any of the above operations can be initiated by the operator. However, in general operation mode, all the above operations except for the scheduling of reception sessions are performed fully automatically. In addition, in the manual mode it is also possible to read from the server files transferred from the STS via FTP. It is necessary when for one reason or another there are unacceptably large data losses during the transfer of data from the STS to the ASC in real time during the session.

The TMKRT subsystem operates on two servers that are running under GNU/Linux. One of the servers is in hot standby while the other is actively used. The determining the difference between the working and backup servers is the address of the network interface. When transmitting telemetry via network the STS decoder always uses the reserved working server as the destination. Usually, both servers of the system are ready to receive data. The used operating system is set up so that when receiving UDP datagrams on port reserved for the reception of telemetry data, it automatically starts the program for copying the data to the disk. All datagrams received since that time and until the forced copy program completion are recorded in a single file. Each server can be in one of two states, i.e., Reception from STS or Test Reception, that differ by the firewall configuration. By default, the working server is in Reception from STS mode, in which the program can receive data only from the network address reserved for the STS decoder. In the Test Reception mode, data can only be taken from the address reserved for the processing system administrator. This mode is used to test the equipment and debug new versions of software. It is a key mode for the backup server. Modes are switched by instructions that can be issued either directly by the system administrator or on their behalf at pre-programmed times. The data transmitted from any address that is not allowed in the current mode are blocked by a firewall and do not enter the system. This eliminates the risk of jamming and loss of received information.

As noted above, the working processing server receives and records all datagrams received from the STS. However, in order to control the OSE operation, data obtained before or after VIRK sessions, for example, when testing the decoder, are of no interest. In addition, for convenience of further analysis, it is desirable that all data related to the same session and their processing results are stored together. To do this, the processing server should be synchronized with VIRK and STS. Such synchronization uses pseudocomments mentioned above in the section GENERATION OF FLIGHT MISSIONS. These pseudocomments are written to the file of the flight mission for each session in which VIRK is used. They contain data about the start and end of pointing of the VIRK antenna at the STS and about what STS will be used to transfer data. Every few hours the program starts on the processing server that scans the table on the data storing server, in which FM files are written that are transmitted to NPOL. If it finds a new flight mission in this table, pseudocomments contained in it are searched for and analyzed, and then a message with the list of newly scheduled VIRK sessions is sent to TMKRT operators. All these operations are carried out fully automatically. When the operator receives the message, they analyze the list, and schedule reception sessions. Usually such scheduling comes down to the launch of the corresponding program that uses the flight mission file as the input. In some rare (about 1%) cases, a slight preliminary modification of the input data file of the reception scheduling program is required. It is necessary in situations where successive VLBI sessions follow closely one after the other, and the interval between them is too small to ensure the execution of all necessary actions for the completion and processing of data of the first session before the start of the second one. In this situation, pseudocomments in the flight mission file are modified and one elongated receiving session is scheduled that comprises several VLBI sessions. The reception session scheduling consists in that times of launch of programs of preparation and completion of reception are appointed using standard operating system instructions (instruction *at*). The preparation program is started 5–10 minutes before the beginning of the VIRK antenna pointing at the STS specified in the FM, and the completion program is launched 1 min after the end of the guidance. The reception preparation program has the following main functions. First of all, the firewall is transferred into a state that prohibits data reception from the STS. This is a temporary ban of ~1 s that guarantees that there will be no external interference in the execution of preparatory operations described below. If the program of reception of data from the STS is running, it is forcibly terminated. All data recorded before or after the session are transferred to a table specially designed for them. Further, the program of the reception monitoring is started that periodically polls the state of the generated file with data obtained from the STS and the network interface, calculates the speed of data reception, and writes the results to the reception protocol. Finally, the instruction is issued to transfer the firewall in the state of data reception from the STS, and the preparation program is completed.

Obtaining of the first datagram from the STS will launch the program that will copy the received data in the data file. In this case, an additional file with metadata describing the origin of the data is created. The same metadata file is used further to store integral characteristics of the session calculated during the data processing. The copying is continued until the data reception is interrupted by the logout program. The logout program closes primarily the access to data from the STS and terminates programs of copying of received data and reception monitoring. Then, based on the reception time of the first VIRK header a unique reception session identifier is created. The so-called *session table* is created with a name consisting of the session ID. The files generated by the reception program are moved to it. After that, the program of processing and rapid analysis is launched. This task of the operating system is executed in the background in parallel with the main task of controlling the overall sequence of actions and independently of it. The last step of the logout program is the switching of the firewall mode in the mode allowing the reception of data from the STS.

PRIMARY TELEMETRY PROCESSING AND OSE RAPID ANALYSIS

From the point of view of the general structure of processing programs, the format of the data transmitted from the STS to the processing server belongs to the family of so-called container formats. Thus, meaningfully the processed stream is the combination of several substreams (TMS parameters DT-parameters, and STS service data) created independently of each other and with a completely different structure. The multiplexing, i.e., unification of independently created substreams in a common stream is performed by the shaper, in the STS hardware, and decoder software, as described above. The first phase of the processing is demultiplexing, i.e., the selection of individual substreams of the total stream of the received data. In this case, the substream of TMS parameters is separated in the first place, and subsequent processing is performed independently from the processing of other substreams. Logically, the separation and processing of this stream can be performed independently. However, for reasons of efficiency and to facilitate both diagnostics of errors, these operations are carried out in a single program. The same program executes the initial phase of the coprocessing of substreams of DT-parameters and STS service information.

The first phase of the primary processing of TMS-P substreams is the allocation of telemetry frames and writing them to the file in the TMI format. The primary treatment of the substream of DT-parameters consists in the averaging of power codes by time intervals of a predetermined duration (usually 1 s). For each averaging interval, the start time of the averaging interval in the onboard time scale, its duration, and the statistical characteristics of power codes are introduced in the generated output TPA file. Files with the original data, processing results, and diagnostic information are transmitted via FTP to the server of the Scientific Data Processing Center of the ASC to the session table created there, which can be read by all participants of the experiment. In order to maximize the response time for emergencies, the automatic analysis of the so-called *fast quality criteria* is performed during preprocessing. These criteria are the parameters that can be obtained from telemetry data that characterize the functioning of the system as a whole. Their marked deviation from the nominal values is likely to indicate anomalies that require operative measures.

At the time of writing of this paper, the share of VIRK frames with zero power codes was used as the main quality criterion. If the proportion of zero codes in the session exceeds a predetermined threshold, then diagnostic messages are immediately sent to experts of the control group and group of reception and processing of telemetry data. The SMTP is used to transfer messages. The recipients receive messages about detected anomalies a few minutes after the session.

CONCLUSIONS

As a result of joint work a high degree of automation of the processes of preparation for the observations and obtaining of service information about them was achieved. The main results of the present paper are as follows

(1) The automatic system of rapid response to emergency modes of the OSE of the SRT was created including the collection and processing of telemetry information and warning system.

(2) The need for manual scheduling and editing of flight missions were reduced.

(3) Processes of preparation and scheduling of observations, as well as the validation of flight missions, were automated.

ACKNOWLEDGMENTS

This work was carried out by the Astro Space Center of the Physics Institute of Russian Academy of Sciences and NPO Lavochkin under contract with the Russian Space Agency together with a number of scientific and technical organizations in Russia and other countries.

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Translated by O. Pismenov