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Construction of a Unified Ground-Based Control Complex for a Multi-Satellite ERS Constellation

A.I. Zhodzishskiy, *Dr. Sci. (Engineering), Prof., contact@spacecorp.ru*
Joint Stock Company "Russian Space Systems", Moscow, Russian Federation
S.K. Zhidkova, *zhidkova.sk@spacecorp.ru*
Joint Stock Company "Russian Space Systems", Moscow, Russian Federation
D.N. Nagornykh, *Cand. Sci. (Engineering), contact@spacecorp.ru*
Joint Stock Company "Russian Space Systems", Moscow, Russian Federation

Abstract. Taking into account the increasing number of spacecraft the further development of the Russian ground control systems (GCS) for Earth remote sensing spacecraft requires new approaches to solving the problems of increasing the efficiency and global control of these spacecraft. The paper considers the possibility of creating a unified GCS ERS SC including the existing GCS ERS SC and providing control capabilities for promising newly created ERS SC. As part of a unified GCS ERS SC a single control center should be created that provides modeling, planning, analysis, and control of future and existing spacecraft constellations and ground-based facilities.

Using international experience in controlling multi-satellite constellations and implementing our own experience in creating special software for the control centers, for new spacecraft constellations, it is proposed to automate the tasks of a typical regular control cycle, automate periodic maintenance operations of spacecraft and localize emergency situations.

To automate control processes, the creation of a digital mathematical model of the orbital constellation and ground-based facilities is also proposed for Russian remote sensing constellations. A model that takes into account and describes the spatio-temporal position of the spacecraft constellations, the location of GCS, ground complex for receiving, processing and distribution (GCRPD), relay satellites (RS), their technical condition, composition and performance should form the basis for the implementation of end-to-end planning of the main control operations and the targeted use of multi-satellite constellations.

Keywords: Earth remote sensing, ground control system, multi-satellite orbital constellations, navigation and ballistic support of the spacecraft, space-time position of the spacecraft

A ground control system (GCS) for automated spacecraft (SC) is a set of technical facilities and structures designed to control SC functioning from the moment of their launch into orbit [1]. A GCS is built for one or more satellites of the same type and consists of the Mission Control Center (MCC, or TsUP), ground stations (GS), command-measuring systems (CMS) providing interaction with SC, communication and data transmission system (CDTS), which integrates elements of a GCS.

Most of domestic civilian GCS SC are built based on the facilities of ground automated control system for spacecraft of scientific and socioeconomic purposes (GACS SC SSP). The peculiarity of the stated GCS is the use of means of a collective access from the composition of GACS SC SSP:

- Multiservice communication and data transmission system (MCDTS).
- Situation analysis, coordination and planning center (SACPC), which ensures the distribution of the GS CMS resource between SC.
- Coordination, operation and development center (CODC) responsible for technical readiness of GACS facilities.
- GS CMS.

Usually the MCC, when creating new GCS SC, is the only newly created product developed for a particular SC or type of SC.

Tasks of SC control performed by means of GCS are solved by conducting communication sessions with each SC in accordance with the long-term and daily control plans. The plans are prepared based on the developed technological control cycles (TCC) of SC and plans for the target use of SC equipment. During the communication sessions, control actions are transmitted to SC, and GCS receives confirmation receipts as a part of the diagnostic information and telemetry information (TMI), which contains data on the status of supporting systems and target SC equipment [3].

GCS solves the following main tasks [4]:

- Preparation of GCS facilities for SC launch and in-flight control of SC.
- SC control during the whole active life cycle including in case of abnormal situations.
- Automated long-term and operational planning of SC control operations and GCS facilities operation.
- Automated preparation of initial data and process information for solving tasks of command and control software, navigational and ballistic support of the SC flight, control of the state and functioning of SC.
- Automated preparation and conduction of communication sessions with SC.
- Automated control of the SC mission program execution based on the accepted TMI both in case of normal functioning and in case of onboard equipment failures and abnormal situations.
- Automated collection, processing, and analysis of all types of information, forming an operational display and documentation of processing results to control the implementation of the process cycle of SC control, the state of on-board equipment of SC and GCS facilities, resource registration as well as accumulation, systematization, and storage of current information about the SC state.
- Measurement of current navigational parameters (MCNP) of SC using CMS, determination and prediction of SC motion based on the results of MCNP and/or data from the SC satellite navigation equipment with the accuracy required for the operation of GCS and ground complex for receiving, processing and distribution (GCRPD)of ERS data.
- Automated exchange of ballistic, command and program, control and operational-technical information within GCS and with external subscribers.

European and American GCS SC ERS differ from Russian ones in the use of ground control facilities located all over the world and belonging to different countries and operators, as a rule, combined with the reception of ERS information. Unification of protocols of all levels of interaction makes it possible to involve means of different operators. Distribution of assets around the world ensures global control and promptness of delivering images to consumers. The most in demand are ground stations located at high northern and southern latitudes, such as SvalSat, TSS, and TrollSat. The SvalSat station located in Spitsbergen (the KSAT operator) provides ground services to more satellites than any other ground facility in the world. The Norwegian operator KSAT has the largest network of ground assets with more than 140 antennas at 21 sites around the world. The PlanetLab ground facility used to control Dove, ScuSati and RapidEye constellations is located at 12 sites and has 36 antennas [5,6].

Further development of Russian GCS SC ERS taking into account the increasing number of SC requires new approaches in solving the problems of increasing the efficiency and global control of these SC. To solve the above tasks it is expedient to consider the possibility of creating the unified GCS ERS, which includes the existing GCS SC ERS and provides control of promising, newly created ERS SC. A unified control center shall be created in UGCS ERS, which ensures modeling, planning, analysis, and control of future and existing ERS SC constellations and ground facilities. Existing ERS GCS will be included into EGCS as independent self-sufficient SC control complexes, but ensuring implementation of the plans of the unified center.

The tasks of MCC UGCS can be divided into tasks of controlling separate SC and tasks of ensuring the operation of the orbital constellation of ERS SC as a whole.

In terms of controlling separate SC, MCC UGCS ERS solves traditional tasks:

1) Navigation and ballistic support (NBS).

2) Command and software support (CSS) including:

- performing a typical SC control cycle;

- providing automatic working programs (WP) insertion via CMS on SC;

- provision of WP insertion via an inter-satellite radio link;

- providing GCRPD with necessary information for planning target operations;

- remote monitoring and control of GS CMS from MCC.

3) Information and telemetry support (ITS) including integral assessment of the SC state.

The tasks to control orbital constellation (OC) in general include the following:

1) Ballistic modeling of the whole OC SC ERS.

2) Maintenance of OC ballistic construction and development of a strategy for introducing new ERS SC into the constellation.

3) Determination of SC OC readiness and ground facilities for fulfillment of user requests.

The increase in the number of SC in OC will lead to an increase and a qualitative change in the ground infrastructure used to control SC and receive ERS data from them. To expand the total radio visibility zones of ground facilities it is proposed to create new sites located mainly in the high northern and southern latitudes: on Spitsbergen, in Antarctica, on the territory of Russia: in Murmansk, Dudinka, Anadyr, and other northern points, which have the infrastructure to create SC control points to receive ERS data from them.

Location of GS CMS in high latitudes will give the greatest number of working turns for SC in low solar-synchronous subpolar orbits. Taking into account GS CMS in Antarctica it is possible to have two control sessions of SC on one turn with an interval of 40 minutes.

Using relay satellites (RS) for operational implementation of working programs (WP) to ERS SC and reception of a limited set of telemetric parameters from them including receipts for the implementation of WP will ensure global and operational control. Newly built ERS SC must be able to be controlled using an inter-satellite radio link and via Luch RS. The images will continue to be transmitted to ground stations (GS) when ERS SC fly over them.

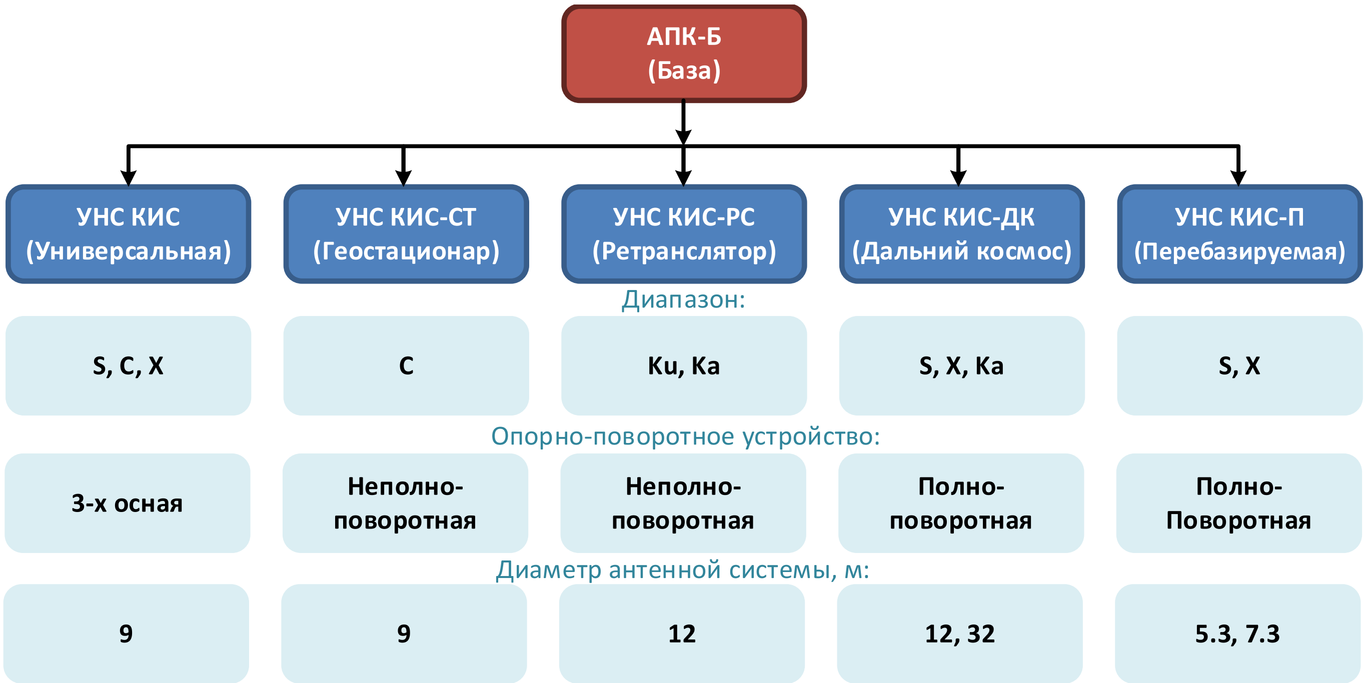
Regulatory documents [7] provide measures to protect telemetry and command-program information circulating in space radio links. The most effective is subscriber closure of the specified information in places of its origin and use, i.e. in SC and MCC. The document [8] contains recommendations on communication security protocol for space data transmission in SC-MCC paths.

UGCS ERS will provide satellite control using both existing ground stations ("Klen", "Klen-R") and prospective unified ground stations (unified GS) CMS. When working with ERS SC it is efficient to use united ground stations (united GS), which combine control of SC and reception of ERS information from them.

A number of unified GS CMS including united GS are proposed to create from unified devices with standard interfaces with SC, MCC and GCRPD. Standard protocols for all levels of interaction will significantly speed up the creation of ground GACS SC SSP facilities. Unified GS CMS will have software-defined structures of signals, multiband antenna systems (AS) or sets of AS with matrix switches, and universal software. Unification of stations will simplify their subsequent modernization, current repairs, and reduce the number of maintenance personnel, provide fast and reliable connection of new subscribers.

Unified GS CMS are developed both in stationary and relocatable (container) versions. Container design drastically reduces the cost of capital construction, allows installing unified GS CMS on ships and in places of temporary operation.

The figure presents the recommended variants of a number of unified GS CMS for implementation. The three-band (S-, C-, and X-) variant of unified GS CMS is essentially a universal GS CMS. The universal GS CMS is fundamentally different from the unified CMS widely used in the United States and Europe. Command and measurement systems consist of onboard equipment and ground stations of CMS. Unified CMS OE (onboard equipment) and GS use unified signal structures and



A number of unified GS CMS based on a common hardware and software complex-B (base) and a set of HF-equipment.

protocols, defined, for example, by CCSDS standards [9], while the universal GS CMS can work with any OE CMS promptly changing the signal structure in a software way.

All ground stations have the same hardware and software complex (HSC-B (base) and differ only in the high frequency (HF) part. HSC-B includes: a digital signal processing module (DSPM), GLONASS user navigation equipment (UNE), personal computer (PC), reference generator, switchboard, and a number of auxiliary devices. Creation and serial production of unified CMS should become the main direction of modernization of GACS facilities in this segment.

The main trend in the development of MCC ERS SC is the automation of SC control and reduction of work shifts by creating an "automatic operator", automatic analysis of TMI, automatic planning of TCC and communication sessions, and automatic response to standard emergency situations (ES) given in the SC documentation.

Traditional approaches to the process of SC control were formed in the 1960s and are implemented in the vast majority of MCC for Russian automatic SC. Moreover, these approaches are identical for the main developers of special software for MCC.

Solution of control tasks is a sequence of operator actions aimed at implementing a typical control cycle for each individual SC. In this case the following tasks are sequentially solved:

- Calculation of SC navigation parameters based on data from onboard satellite navigation equipment and/or current navigation parameters measurements (CNPM) of ground facilities.
- Forming applications for the employ of shared use.
- Long-term and operational planning of SC operation.
- Integration of the target equipment into the work program plans.
- Formation of a control session and its implementation by means of unified GS CMS.
- Receiving telemetry information, receipt information, CNPM, time reconciliation results, information of the functional control of GS CMS, and other reporting data during the control session (or after its completion).
- Analysis of the technical condition of the onboard systems and target equipment of SC based on the telemetry received.

Nowadays standard TCC operations are automated, but are not performed automatically, and contain a rather large number of manual operator actions even when performing routine, repetitive tasks. Automation of the process is mainly due to the creation and storage in the database of typical operations (TO), which combine control actions. Typical operations are subdivided into regular (TO of session start, TO of CNPM, etc.), and typical operations of ES localization. These ES are included in long-term and operational plans or implemented directly in the course of a control session.

Some MCC automate the creation of a typical session and automatically execute a control session based on the feedback of receipt information. With such an approach to organization control, an increase in the number of SC in the constellation will inevitably lead to reaching the limits of the capability to provide control and target use of the SC constellation. Increasing the number of personnel and automated workstations will not be an effective solution to the problem.

Using foreign experience to control of multi-satellite constellations and implementing our own developments in creating special software for MCC, for new SC constellations we propose to automate as much as possible the performance of tasks of the typical routine control cycle (operations of NBS, ITS, CSS), to automate periodic operations on maintenance of SC and automate the localization of ES given in the documentation. In other words, it is necessary to create automatic scenarios of SC control based on the scenarios given in the operational documentation.

These scenarios will make it possible to automate TCC and automatically respond to ES identified in the process of automatic analysis of TMI. At the same time it is necessary to impose increased requirements for work on the maximum possible autonomy of SC with the transfer on board a greater number of both periodic operations and operations on automatic localization of spent ES.

To localize unworked ES or undescribed in the documentation it is advisable to create a “paging” system (SMS, e-mail) to notify the developers of SC, flight managers, developers of MCC, and GS CMS. The implementation of this way will lead to automation of SC control and minimization of the number of operators. In addition, such a system will minimize the participation of sectors of the chief designer in SC control both at the stage of flight tests (FT), and at the stage of normal operation.

It should be noted that the transition to automatic SC control (creation of an “automatic operator”) cannot happen at one time. The process of automation requires sufficient efforts of the developers during SC creation. At the stage of FT and operation, SC developers and special software (SS) MCC are joined in the improvement of automatic processes by SC operators, who propose to automate periodic, repetitive processes identified at the stage of SC control. To debug and implement new automatic SC control scenarios, hardware-software and (or) software models of SC are required, on which the correctness of automatic scenarios is tested before their implementation in the control process and SS MCC.

For domestic ERS orbital constellation, in addition to the above ways of automating the control processes, the creation of a digital mathematical model of the orbital constellation and ground facilities is also proposed. Mathematical model should contain full actual ballistic information about each SC at any moment of time, readiness of SC to fulfill the target task (operability of supporting systems and target equipment, free intervals for imaging taking into account restrictions), actual state of ground control complex with definition of possibility of SC insertion (coordinates of unified GS CMS with consideration of SC radio visibility zones, current state of GS CMS equipment with generalized sign of readiness for a laydown session, dynamically updated free time intervals), and current state of GS RPD with the possibility of target information (TI) reception.

A model that takes into account and describes the spatial and temporal position of the orbital constellation SC, the location of retransmission system (RS), GCS, and GC RPD facilities, their technical state, composition and operability should form the basis for the end-to-end planning of basic control operations and target application of the multi-satellite orbital constellation.

Such a model should consist of mathematical models combined through input and output parameters:

- Orbital constellation.
- Ground control complex.
- Ground receiving, processing and distribution complex.
- Multifunctional space retransmission system.

The consumer's application, submitted to the model input, must automatically pass the stage of selecting the optimal implementation parameters:

- SC, which will perform the survey.
- GS CMS (unified GS CMS or united GS), which will carry out the working program implementation;
- Receiving station of TI (united GS), which will receive the results of the survey.

In this case, all subsequent operations on SC planning up to the laying of command amd measurement information (CMI) and WP on SC directly from GS or through RS are carried out in MCC in automatic mode.

For gradual transition of the whole constellation of ERS SC to digital model of consumer's request implementation it is proposed to include already functioning GCS ERS SC. Against the background of the existing typical SC control cycle in the existing MCC it is reasonable to separate the automatic passage of the operational request for imagery. The request with an "urgent" status goes to the digital model of the orbital constellation. Based on the results of the operation of the digital model, SC for WP insertion and the means of insertion (GS CMS or "Luch" RS) are determined. The incoming request in the form of WP is transmitted to the appropriate MCC or to a single ERS MCC and is laid down on SC in the automatic mode "over" the current control processes (execution of TCC).

Conclusion

The main ways to build a unified GS CMS for multi-satellite constellation of ERS SC are the following:

- Use of unified range of GS CMS including united GS.
- Unified GS CMS deployment at high latitudes.
- Using RS for operational programming and SC condition vector reception.
- Implementation of the "automatic operator" function.
- Using unified MCC for control over advanced ERS SC and gradual integration of existing ERS SC into it.
- Transition to unified information and control system for MCC SC based on standards.
- Application of subscriber information closure to use different ways of access to SC (via RS and unified GS CMS).

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