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RADIOASTRON FLIGHT OPERATIONS

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1.0 INTRODUCTION

Radioastron is a space very-long-baseline interferometry (VLBI) mission to be operational in the mid-90s. The spacecraft and space radio telescope (SRT) will be designed, manufactured, and launched by the Russians. The United States is constructing a DSN subnet to be used in conjunction with a Russian subnet for Radioastron SRT science data acquisition, phase link, and spacecraft and science payload health monitoring. Command and control will be performed from a Russian tracking facility.

In addition to the flight element, the network of ground radio telescopes which will be performing co-observations with the space telescope are essential to the mission. Observatories in 39 locations around the world are expected to participate in the mission.

Some aspects of the mission that have helped shaped the flight operations concept are: separate radio channels will be provided for spacecraft operations and for phase link and science data acquisition; 80-90% of the spacecraft operational time will be spent in an autonomous mode; and, mission scheduling must take into account not only spacecraft and science payload constraints, but tracking station and ground observatory availability as well.

This paper will describe the flight operations system design for translating the Radioastron science program into spacecraft executed events. Planning for in-orbit checkout and contingency response will be discussed, also.

2.0 FLIGHT ELEMENTS

The Radioastron flight elements, shown on Figure 1, include the Spectr-R spacecraft and the space radio telescope. The spacecraft will operate in a highly elliptical orbit with an apogee of 80,000 km, perigee of 2000 km, and a 28-hour orbital period.

2.1 Spectr-R Spacecraft

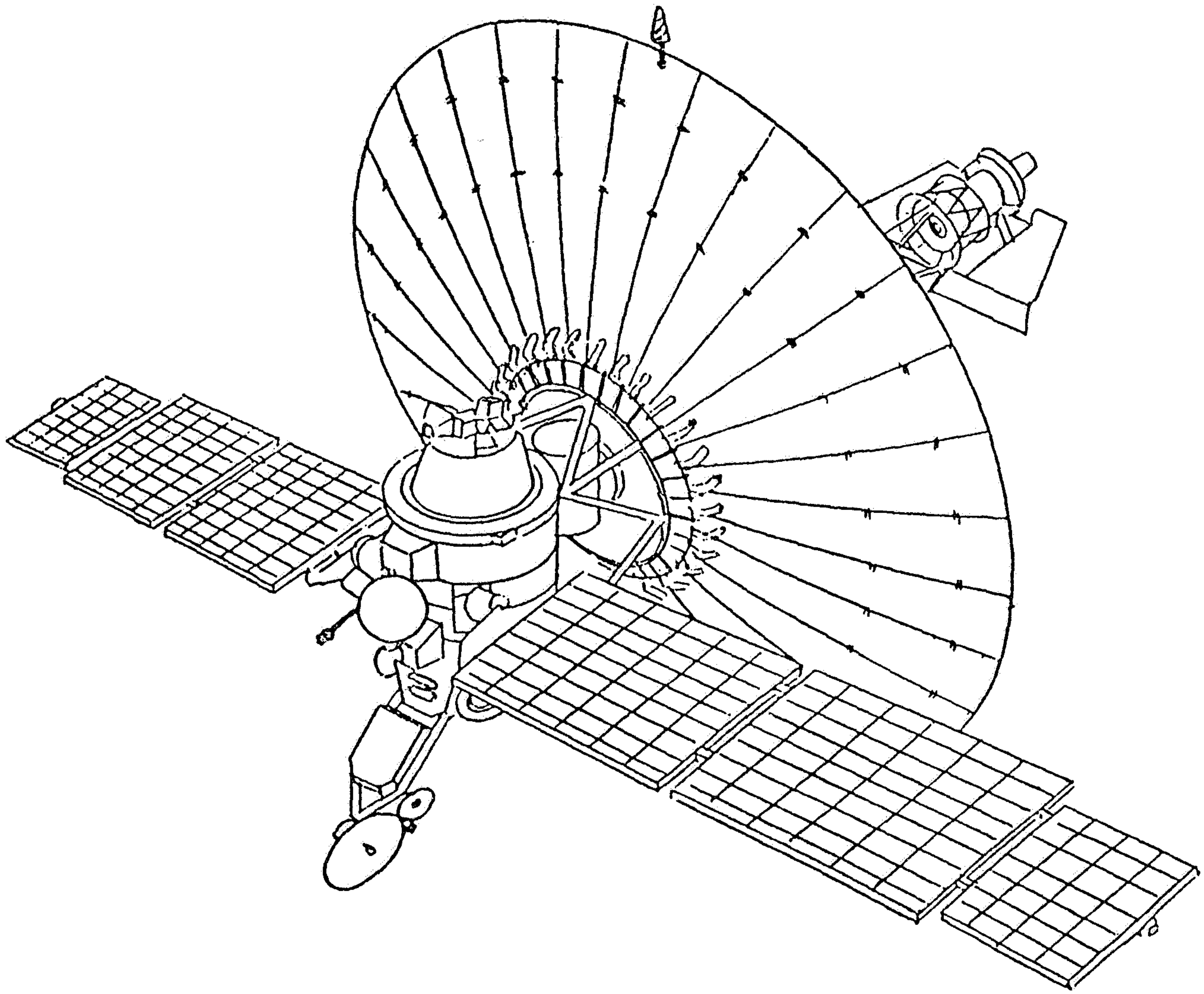
The Radioastron spacecraft is part of the Spectr series of spacecraft which was designed for astrophysics research by the Russian space industry in response to a request by the Russian Academy of Sciences. The Spectr bus will be common to three separate astrophysics missions - Spectr-Radioastron, Spectr-X Gamma (for X- and gamma-ray research) and Spectr-UV (for research in the ultra-violet portion of the spectrum). The spacecraft bus design is based upon the designs of previous Russian spacecraft. The 3 spacecraft all share, among other things, the same commanding and telemetry systems (Main Radio Complex, MRC) which will operate in C- and P-band, a central processor with onboard memory (Time Program System, TPS), power supply system, a 3-axis stabilized attitude control system which provides pointing accuracy of up to 1 arc minute, solar panel orientation system, and propulsion system. All of these critical systems are redundant except for the propulsion system.

2.1.1 Spacecraft Commanding

The spacecraft will be operated through the MRC. Commands will be transmitted from the ground at a maximum of 10bps through the radio system which receives and decodes the commands. Thereafter, they

FIGURE 1

RADIOASTRON SPACECRAFT



will be distributed to the TPS. The basic function of the TPS is that of a dispatcher of spacecraft and science payload operations that are controlled (activated, deactivated, mode selected) by the corresponding TPS programs.

TPS programs may be started and stopped by functional or numerical commands transmitted from the ground during the daily communication session. The entire memory of the TPS is 10KB which is divided into two areas: flight software and flexible programs.

2.1.2 Spacecraft Telemetry

The telemetry (TM) system is a software-hardware package that is incorporated into the MRC and is used for acquisition, conversion and storage of telemetric information from the spacecraft and science payload. The TM information data rate is 1 Kbps. Approximately 40 MB of TM data can be stored onboard. The data will be acquired in real time or dumped from the recorder using the C- or P-band channel during the daily communication session.

2.2 Space Radio Telescope

The Radioastron science payload consists of a high precision 10m-diameter deployable antenna and four radio-astronomical receivers working at the following wavelengths: 92cm, 18cm, 6cm, and 1.35cm with dual circular polarization. Any two of the receivers can operate simultaneously at the same polarization or one receiver can be operated in the dual polarization mode.

The science payload includes 8 subsystems which are controlled through the C- and P-band radio complex and TPS during the communication session. Commands either can be stored in the TPS or transmitted in real time. Information about the health of the science payload is transmitted to Earth through the TM system and C- and P-band radio complex.

3.0 RADIOASTRON TRACKING

The tracking facilities to be used for Radioastron are one of the primary elements of the ground support segment of the space VLBI mission [1] as are essential to spacecraft and science payload operations.

3.1 Radio Channels

The Spectr-R spacecraft will have four radio channels to communicate with ground support systems. Commanding, TM monitoring of the spacecraft and science payload, and navigation measurements (range and range rate) will be performed using the C-band channel (with P-band as a backup).

The signal from the radio astronomical receivers will be transmitted to Earth through the High Information Rate Radio Complex (HIRC). It will be digitized, formatted, and transmitted by a Ku-band transmitter. The maximum science data rate is 144 Mbps. To support the SRT as part of an Earth-space interferometer, a high-stability signal from a ground-based hydrogen maser standard is transmitted to the spacecraft through the X-band radio link. The spacecraft, in turn, will retransmit the signal to Earth. The signal will be used for navigation measurements (Doppler) and for phase residual measurements which will be used to process the Earth-space interferometric data. The C-band channel can be used as a phase link backup when not in use for satellite control.

The spacecraft control session using C-band can take up to 4 hours during the 28-hour orbital period. The separation of the spacecraft control and science data radio channels provides the possibility to do science observations during a control session (although this is not recommended due to possible interference effects). This could increase the science return of the mission, especially during the in-orbit checkout period when the control sessions are expected to occupy a majority of the operational period. Another advantage to separating the channels is that the C-band channel can then be used as a backup for the X-band phase link.

The DSN subnet to be used for science data acquisition and phase link will be equipped to work only at X- and Ku-bands, not C-band. Thus, the spacecraft can be controlled only during times it is tracked by Russian tracking facilities. Because the spacecraft will be operating autonomously 80-90% of the time, it was decided for contingency recognition purposes that spacecraft and science payload health data should be included in the science data frame header which will be acquired by the tracking stations together with the high-rate science data stream through the Ku-band radio channel.

3.2 Tracking Facilities for Spacecraft Operations

Radioastron will be operated in Russia from the Satellite Control Center (SCC) through the tracking network located on the territory of the former USSR in Ussuriisk and Evpatoria (both are 32m antennas working in P- and C-bands) and near Moscow (25m antenna working in P-band). The SCC connects with the tracking stations both by telephone (2.4 Kbps) and satellite communication lines (64 Kbps). The same tracking station network will receive TM from the spacecraft and science payload and send this information to the SCC for analysis by the spacecraft and science payload analysis teams. The navigation measurements at C-band (range and range rate) also will be executed by the tracking stations and the results forwarded to the Navigation Centers located in Moscow.

3.3 Tracking Facility for Phase Link and Science Data Acquisition

To optimize the science return and to provide continuous coverage of the space element, a world-wide tracking network is being constructed to support Radioastron. This network will include one Russian tracking station located in the Russian Far East (Ussuriisk) and three US DSN 11m tracking stations (Goldstone, Madrid, Canberra) and a 14m antenna in Green Bank. The US Space VLBI Office at JPL will be responsible for managing the US-sponsored portion of the tracking network (which will also support operations of a Japanese space VLBI mission - VSOP) and the Astro Space Center of the Russian Academy of Sciences in Moscow will be reponsible for the Russian portion.

The science data flow (144 Mbps) will be recorded at the tracking stations as well as phase residual measurements (30 Kb per day) and sent to the Data Processing Facility (DPF). There will be one each in Russia and the US. The DPFs will process data from the SRT and the co-observing ground telescopes. The X-band Doppler measurements from the tracking stations (30 Kb per day) will be sent to the Orbit Determination Centers (ODCs) - one each in Moscow and Pasadena to be used together with C-band range and range rate measurements for orbit predictions and reconstruction. The orbit reconstruction data, required for the correlation process, will be based on about two weeks of measurements. The orbit predictions (Doppler, state vectors) will be sent daily to the SCC and tracking facilities to support operations.

Two of the tracking stations (Ussuriisk and Green Bank) will be equipped with diagnostic correlators to provide near-real time end-to-end system verification of the Earth-space interferometer. These two stations were chosen because they are co-located with ground radio telescopes. At these stations, the high-rate science data from the space element and the science data from the ground telescopes can be processed a few minutes after the observations. The results will be sent to the General Operative Control Group (GOCG) and Radioastron Science Operations Group (RSOG) to show the status of the interferometer. Using the diagnostic correlator will be very important during the in-orbit checkout phase.

4.0 FLIGHT OPERATIONS

The mission operations concept for the Earth-space VLBI mission was described in [2]. The following focuses on the flight operations element.

4.1 In Orbit Checkout

Routine operations for the Radioastron spacecraft and SRT will begin after a 3-month in-orbit checkout (IOC) period. During IOC, the critical spacecraft systems and science payload will be fully tested. Some science data will be collected during this period.

The IOC period will be divided into three phases:

(1) The first 2 -4 weeks will be dedicated to checking the spacecraft systems - the Main Radio Complex, Attitude Control and Power Supply systems.

(2) The second phase will consist of a checkout of the science payload in conjunction with the spacecraft. The Attitude Control System will be retested after the SRT has been deployed because the mass distribution of the spacecraft will change due to the size of the antenna (10m) and mass (800 kg) which is about 20% of the mass of the spacecraft. The attitude control system can be calibrated in parallel with boresighting of the SRT. The SRT characteristics will be checked simultaneously with the thermal control system of the spacecraft.

(3) The final phase will consist of the end-to-end checkout of the Earth-space interferometer by using a diagnostic correlator.

During IOC, spacecraft and science payloads in Russia usually are monitored autonomously by the GOCG. In the case of Radioastron, however, the end-to-end testing of the space elements together with the ground elements is of extreme importance because of the unique relationship between the two elements in an Earth-space interferometer experiment. Therefore, operations during IOC will be executed in real time.

4.2 Routine Operations

The orbital parameters of the spacecraft and the mission planning cycles will govern, to a large extent, routine flight operations for Radioastron. The mission planning cycles for Radioastron are based upon usual ground VLBI and Russian spacecraft operations practices: (1) The minimum amount of time required to change a spacecraft science observing command file is 2 - 3 days; (2) The observing program for Russian space science missions usually covers a month's worth of observation sources; (3) Time commitments for co-observations with ground radio telescopes usually are made one year in advance; (4) Announcements of Opportunity (AO) are usually released one year in advance of the observations covered by the particular AO.

The GOCG, resident at the SCC, will be responsible for preparing the spacecraft command sequences based upon the observation requests generated by the observers and RSOG. The RSOG will create the science payload command sequences. The command sequences will be generated with the assistance of software which identifies activities in vioation of spacecraft and science payload constraints. The GOCG will process the sequences through a hardware and software command simulator prior to transmitting the command files to the tracking station where they will be stored for 2 -3 days before being uplinked.

After the commands have been uplinked, the GOCG will verify that the commands have been properly loaded on the spacecraft and payload. During this time, also, the onboard TM recorder will be off-loaded and real-time TM will be received.

4.3 Contingency Response

During the analysis of the TM data, if spacecraft or science payload anomalies are recognized, the spacecraft and science payload system experts will attempt to diagnose and resolve the problem. They will follow an established set of procedures for identifying the source of the onboard anomaly. The first source to be checked is the tracking system. This is followed by the main radio complex, power supply system, and finally the attitude control system. In prior missions, when an attitude control problem has arisen, it has taken about 2 hours to deduce that it is the source of the anomalous condition. The length of the response time is due to the reluctance to meddle with the attitude control system. Given that time is of the essence when dealing with an attitude control anomaly, the Russian spacecraft team is hoping to generate a new contingency response "tree" to accelerate the identification of the source of the anomaly.

During times when the US-sponsored tracking stations are tracking the spacecraft, they will record and send to the Project Operations Control Center at JPL in near real time, a certain number of blocks of science header data per second. As mentioned earlier, this data will include information on the spacecraft and science payload health. Alarm limit software at JPL will enable GOCG's spacecraft team to be alerted if an anomaly has occurred.

5.0 CONCLUSIONS

The complexity of an Earth-space interferometry mission results in large part from the need to coordinate many disparate elements. During the design stage of the Project, the decision was made to improve the flight control loop of the mission through, for instance, the inclusion of spacecraft TM in the science data header and the use of a diagnostic correlator. The flight operations concept for Radioastron is a unique one, reflecting the uniqueness of an Earth-space interferometric system.

6.0 REFERENCES

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