# Ground Systems Supporting Satellite Operations

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**Abstract**

To enable a satellite to complete its missions, it is necessary to prepare a ground system equipped with a satellite control function to monitor the satellite's status and control it, functions to receive the various types of data acquired by the satellite, etc.

NEC aims to develop an internationally competitive ground system through standardization, by packaging the required functions and developing technology elements to meet the latest trends.

**Keywords**

satellite operations, ground system, satellite control, satellite tracking and control
data reception, orbit determination, high-precision orbit determination

## 1. Introduction

To enable a satellite to complete its missions, it is necessary to prepare a ground system to control and operate the satellite, receive the data acquired by the satellite, etc.

At NEC, we have the highest market share in Japan in the field of satellite ground systems, playing an active role throughout the system life cycle, from development and system integration to the operation and maintenance of wireless transmission/reception equipment to operations software.

This paper gives an outline of a satellite operations ground system, the efforts we are making to package the system and the trends and development situation of satellite operations-related technologies.

## 2. Outline of a Satellite Operations Ground System

A satellite operations ground system plays the roles of monitoring/controlling the mission execution of the satellite, maintaining/managing the satellite and supporting mission operations using a satellite control function to monitor the satellite's status and control its mission execution, using a mission data reception function to receive the mission data acquired by the satellite and transmit it to a processing function, etc. The rest of this section gives an outline of the satellite control and mission data reception subsystems that implement these functions.

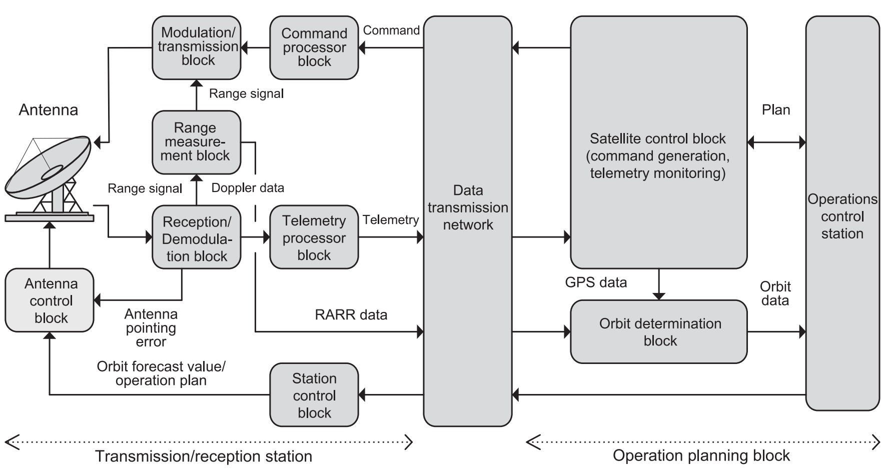



Fig. 1 Example configuration of a satellite control subsystem.

### 2.1 Satellite Control Subsystem

The satellite control subsystem monitors satellite status with telemetry so that the satellite can accomplish its missions reliably. Its satellite control function sends satellite control instructions and mission operation programs as commands. It also has an orbit determination function to determine the satellite's orbit.

The configuration function, satellite control function and orbit determination function of this subsystem are described below.

**(1) Configuration**

**Fig. 1** shows an example of the configuration of a satellite control subsystem.

In general, a satellite control subsystem consists of transmission/reception stations for direct communications with the satellite and an operations control station for monitoring and controlling satellite status and determining the satellite's orbit.

In the most general system configuration, transmission/reception stations are installed in several locations to increase communication opportunities, improve orbit determination precision and back up operations in case a station stops working due to a disaster or bad weather, and they are connected with the operations control station through a network.

Each transmission/reception station consists of an antenna, an antenna control block, a modulation/transmission block, a reception/demodulation block, processor blocks for processing the command data controlling the satellite and telemetry data indicating the satellite's status, a station control block, etc.

The operations control station consists of a satellite control block, which generates command data and monitors telemetry data, an orbit determination block, which calculates the satellite's orbit, and an operation-planning block.

**Photo 1** , **Photo 2** and **Photo 3** show pictures of the antenna, transmission/reception equipment and satellite control equipment of a quasi-zenith satellite tracking and control system as an example of a satellite tracking and control system.

**(2) Satellite control function**

A transmission/reception station builds a communications link by pointing an antenna toward the satellite using the orbit forecast value generated by the operations control station or by automatically tracking the incoming radio wave's direction. The wireless communication frequencies used are usually in the S band (2 GHz) or Ku band (12 GHz), but some scientific satellites use the X band (7 to 8 GHz) and some positioning satellites use the C band (5 GHz).

After a communications link is built, the transmission/reception station receives and demodulates the satellite's telemetry data, processes it with frame synchronization and error


Photo 1 φ7.6-meter transmission/reception antenna.


Photo 2 Transmission/reception equipment.


Photo 3 Satellite control equipment.

correction and then transmits it to the satellite control block. The telemetry data indicates the operating status and health of each subsystem in the satellite. The satellite control block uses it for limit monitoring and management based on the statistical processing of long-term tendencies.

The satellite control block also generates the command data for controlling the satellite's attitude, orbit and payload according to the satellite's operation plan and modulates the data in a transmission/reception station for transmission to the satellite. A function is also provided to check the execution results of each transmitted command and to retransmit as required.

The satellite control subsystem may sometimes be equipped with a function to check satellite behavior by running a computer satellite simulator before transmitting the command.

The data rate of telemetry and command transmissions ranges from a few to some hundreds of kbps, which is relatively low compared to the data rate of the data reception subsystem described later.

**(3) Orbit determination function**

This function determines the satellite's orbit and forecasts its future orbit. The orbit determination result is used to confirm the satellite's flight path and to forecast the data transmission/reception start time and antenna pointing angle, and also as satellite information for use in satellite operations planning and data processing.

When the orbit determination result is used for orbit confirmation and forecasting, the range and range rate method is used, based on the range (distance) between the transmission/reception station and the satellite and the range rate (distance change rate or velocity). The orbit determination error with this method is between some tens of meters and 1 km.

Range is calculated by transmitting a range measurement signal from the transmission/reception station, receiving the signal sent back by the satellite and measuring the two-way propagation time. Range rate is calculated from the size of the Doppler frequency shift of the signal received from the satellite.

On the other hand, when the orbit determination result is used in mission data processing, such as the mapping of satellite images, precision below a few meters is required. In this case, high-precision orbit determination using GPS data is applied, in which the satellite receives GPS signals and transmits them to the ground so that they are corrected in the ground system, making it possible to measure the orbit with high precision. At this time, correction based on Satellite Laser Ranging (SLR) is sometimes combined with this method. With SLR, a laser reflector is installed on the antenna and range is measured from the round trip time of the laser. SLR equipment in Japan is prepared by us at NEC.

## 2.2 Mission Data Reception Subsystem

The mission data reception subsystem receives the data acquired by an Earth observation satellite or scientific satellite, stores it temporarily and then transmits it to the data processor block.

**(1) Configuration**

**Fig. 2** shows an example configuration of a mission data reception subsystem.

This subsystem consists of an antenna, an antenna control block, a reception/demodulation block, a preprocessor block, a recorder block and a station control block. It is sometimes connected to the mission data processor block and satellite control station through a network, as shown in the figure, but there are also cases in which all of the equipment is installed in a single location.

**(2) Data reception function**

The mission data reception subsystem establishes a communications link by pointing an antenna toward the satellite using the orbit forecast value generated by the operations control station or by automatically tracking the incoming radio wave's direction. Its wireless communication frequency is usually in the X band (8 GHz).

After the communications link is established, the mission data reception subsystem receives and demodulates the mission data, preprocesses it (this includes format synchronization, error correction, etc.), stores it temporarily and then transmits it to the data processor block for image processing, etc. As the allocation of processing operations within the data processor block is determined by taking operational conditions and the network environment into consideration,

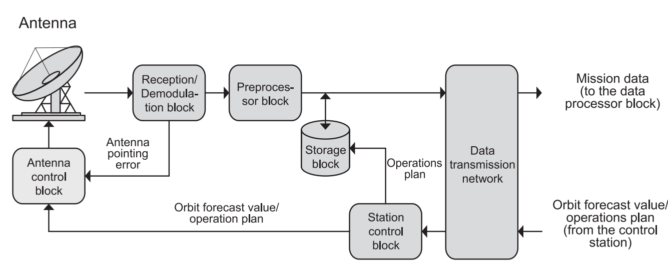
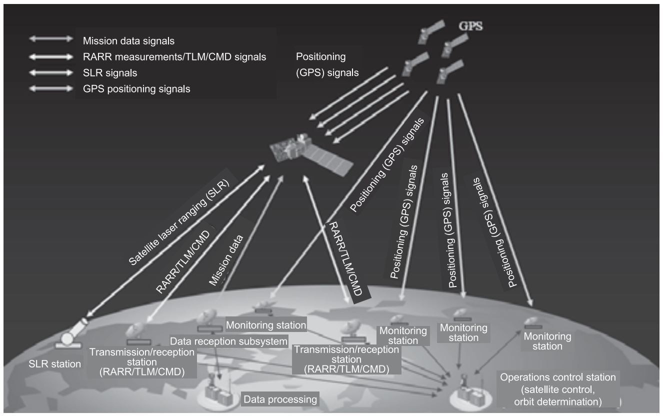



Fig. 2 Example configuration of a data reception subsystem.




RARR: Range And Range Rate, TLM: Telemetry, CMD: Command

Fig. 3 Structural principles of a satellite operations ground system.

it is variable between ground systems.

As the transmission of data from an Earth observation satellite requires a high transmission rate (hundreds of Mbps), broadband data receivers, high-capacity recording media and high-speed data transmission networks are prepared for this purpose.

**Fig. 3** shows the structural principles of a satellite operations ground system containing satellite control and data reception subsystems.

## 3. Ground System Packaging Efforts

NEC is tackling the development of a standard ground system that packages operations control and mission data reception functions.

**Table** shows the main specifications of a standard ground system.

This standard system is compliant with the data communications standards established by the Consultative Committee for Space Data Systems (CCSDS) and has the universality to make it usable both inside and outside Japan. NEC's use of standard products enables both the flexibility of enabling the early incorporation of advanced functions and cost reduction.

## 4. Development Situation and Trends in Satellite Operations–Related Technologies

Most satellite operations technologies utilize already-established technologies, in consideration of reliable operation.

Table Main specifications of a standard ground system.

| | |
|---|---|
| Antennas | |
| Type | Cassegrain reflectors, triaxial mount (AZ, EL, Cross-EL) |
| Reflector diameters | 7.6 m, 11 m, 13 m (other diameters made to order) |
| Drive performance | AZ: ±270°, EL: 0 to 180°, satellite altitude 400 km, all-sky tracking |
| S-band TTC transmission/reception | |
| Command transmission | |
| Transmission power | 200 W (other wattages made to order) |
| Frequency | 2,025 to 2,120 MHz |
| Modulation methods | PM, PSK-PM, BPSK, QPSK |
| Bitrates | PM, PSK-PM, BPSK: 100 bps to 1.2 Mbps<br>QPSK: 10 kbps to 2.048 Mbps |
| Baseband processing | CCSDS-compliant |
| Error correction coding | Convolution (K = 7, R = 1/2), RS (255, 223), CRC |
| Transmission method | CLTU |
| Telemetry reception | |
| Frequency | 2,200 to 2,300 MHz |
| Modulation methods | PM, PSK-PM, BPSK, QPSK |
| Bitrates | PM, PSK, BPSK: 100 bps to 1.2 Mbps<br>QPSK: 1 kbps to 2.048 Mbps |
| BER deterioration | ≤ 2.0 dB (1 dB typical) |
| Acquisition frequency range | ≥ ±200 kHz |
| Baseband processing | CCSDS-compliant |
| Error correction decoding | Viterbi decoding, RS decoding |
| Transmission methods | VCDU, ASD* |
| Ranging | |
| Measurement methods | PN code method, sidetone method |
| Max. measurement range | ≥ 75,000 km equivalent |
| Measurement resolution | 1 ns equivalent |
| Measuring signal frequencies | 500 kHz, 100 kHz |
| Acquisition time | ≤ 10 sec. (PN code), ≤ 15 sec. (sidetone) |
| Measurement precision | ≤ 1 $m_{RMS}$ (500 kHz measurement, S/No: 38.8 dBHz) |
| Range rate measurement | |
| Measurement method | Integrated Doppler measurement |
| Measurement range | ≥ 15 km/s |
| Measurement phase resolution | ≥ 360°/4096 |
| Measurement precision | ≤ 1 cm/sec. (S-band reception, C/No: 40 dBHz) |
| X-band data reception | |
| Frequency | 8,025 to 8,400 MHz |
| Modulation methods | BPSK, QPSK, OQPSK, 16QAM |
| Bitrates | BPSK: 1 to 250 Mbps<br>QPSK, OQPSK: 2 to 500 Mbps<br>16QAM: 400 to 850 Mbps |
| BER deterioration | ≤ 2.0 dB (1 dB typical) |
| Acquisition frequency range | ≥ ±1 MHz |
| Baseband processing | CCSDS-compliant |
| Error correction decoding | Viterbi decoding, RS decoding |
| Data transmission methods | RAW, VCDU |
| Data storage capacity | 2 TB (extension available) |
| Transmission protocols | FTP, socket transmission* |

* Optional

Nevertheless, as recent increases in mission data transmission rates and enhanced requirements for secrecy and interference immunity for satellite control have been advancing studies in improving communications and signaling methods, we are developing technology elements to meet this trend.

**(1) Improved mission data transmission rates**

Recent requirements in the field of Earth observation for expanded observation area and increased resolution are making it necessary to substantially increase the volume of observation information ( **Fig. 4** ).

On the other hand, with low-altitude Earth-orbiting satellites taking a polar orbit, such as Earth observation

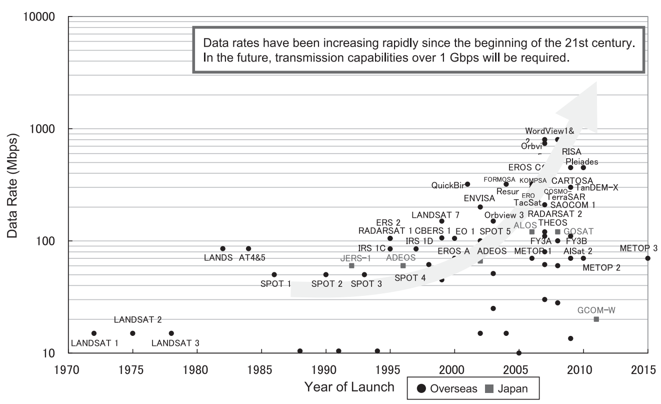



Fig. 4 Changes in the data transmission rate of Earth observation satellites (NEC survey).

satellites, the period of each satellite communication session can be as short as 10 minutes, and the number of communicating opportunities per Japanese reception station is limited to 4 or 5 times a day.

To increase the frequency and duration of opportunities for communication, countermeasures such as constructing reception stations in high-latitude areas and relaying data using geostationary satellites have already been put to practical use.

To deal with the transmission rate limit imposed by the bandwidth restriction defined in the Japanese Radio Act, polarization multiplexing technology is now being put to practical use. This can improve bandwidth utilization efficiency by using polarized waves with different modes of propagation.

Use of the Ka band (20 to 30 GHz), in which a broad frequency band can be used, may enable increases in transmission rate. However, use of this band is accompanied by the problem of substantial power attenuation due to rain, which leads to a drop in the availability of communications circuits. Therefore, increases in data multiplicity by means of multilevel modulation are being studied because they are expected to increase transmission capacity in a narrow frequency band.

The current mainstream standard is 2-bit simultaneous transmission based on quadrature phase-shift keying (QPSK). 4-bit simultaneous transmission based on 16-quadrature amplitude modulation (16QAM) is scheduled to be implemented, and we at NEC have already developed asatellite-borne modulator and a terrestrial demodulator for it. As it is estimated that the number of phases may increase to 64 in the future, there are high expectations for the results of developing this technology because increasing the number of phases will make it possible to increase transmission rates.

**(2) Improved security for satellite control/operations**

Satellite use in the security field requires an even higher security level for operational information, such as observation locations and frequencies, than that required for the mission data collected by the satellite. This leads to a requirement for high secrecy for satellite control/operation commands and telemetry data, and also makes it necessary to study countermeasures against denial-of-service attacks based on command spoofing.

These countermeasures may be made possible by introducing spread-spectrum communication techniques in addition to using multiple frequencies (frequency hopping, etc.). For spread-spectrum communication, we have already completed the development of a command/telemetry data modem using CDMA modulation and have tested its transmission/reception using an in-orbit satellite. We are presently accumulating more expertise in this area.

## 5. Conclusion

This paper outlined a ground system supporting satellite operations and introduced packaging efforts, technical trends and the overall development situation.

Growth of the space-related market, focusing on Earth observation, is expected worldwide, and an increasing number of overseas projects are requesting the supply of packages combining a satellite and its operations system.

Based on this market trend, we are planning to develop and promote internationally competitive package systems by making use of our strength, which is NEC's capability to develop both satellites and ground systems in-house.

### Author's Profile

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