OPERATIONAL ACHIEVEMENTS WITH JAPANESE BROADCASTING SATELLITE FOR EXPERIMENTAL PURPOSE (BSE)

Susumu Shimizu
National Space Development Agency of Japan
2-4-1, Hamamatsu-cho, Minato-ku, Tokyo 105, Japan

Katsuyoshi Arai
Tsukuba Space Center, National Space Development Agency of Japan
2-1-1, Sengen, Sakura-mura, Ibaraki 305, Japan

Summary

Sophisticated operational achievements reached with the Japanese Medium-scale Broadcasting Satellite for Experimental Purpose (BSE) are introduced.

After initial checkup of the spacecraft functions in geostationary orbit, various TV broadcasting experiments have been started out on July 20, 1978. On performing these experiments, such operations as house keeping and station keeping together with attitude control have been in charge of National Space Development Agency of Japan (NASDA).

This paper provides information on the operational achievements in these areas reached with the zero-momentum three-axis stabilized spacecraft during about one and a half years.

Introduction

Since July 1978, subsequent to the convincing initial checkup of the spacecraft functions on geostationary orbit of 110°E, experiments on satellite broadcasting in 12GHz band have been performed by the Radio research Laboratories (RRL) of Ministry of Posts and Telecommunications (MOPT) in cooperation with both Japan Broadcasting Corporation (NHK) and NASDA.

On performing these broadcasting experiments, properly managed such operations as station keeping, house keeping together with attitude control have fully been in charge of NASDA.

As the BSE is the first spacecraft in Japan having direct television broadcasting function with high technology of zero-momentum three-axis stabilized subsystem for its attitude control in geostationary orbit, every operational efforts have served enhancing maneuvering ability with the spacecraft and brought about valuable flight data in this field. The variety of results have revealed some interesting features in the area during about one and a half years.

In this paper, some operational acheivements with the BSE reached at mainly Tsukuba Space Center (NASDA) are introduced concentrating on characteristic results of the station keeping and house keeping including spacecraft attitude behavior.

Outline of the spacecraft

BSE system parameters

Major system parameters of the BSE are shown in Table 1.

Table 1. Major system parameters of the BSE

Spacecraft weight	678.4 kg (approx. 356 kg in orbit)
Attitude control	Zero-momentum three-axis stabilized system
Beam pointing accuracy	±0.2°(except for eclipse period)
Spacecraft location	110° East longitude
Station keeping accuracy	±0.1° in E-W, N-S direction
Fuel	34.156 kg
Design life/Reliability	3 years/o.725
Number of TV channels	2
Telemetry and command	S band and K band

Configuration of major attitude control components

The static infrared earth sensor is usually selected for both pitch and roll, sensing errors with respect to the center of the earth. A pair of sun sensor assembly, diagonally installed on the north and the south solar panel, are usually selected for yaw. The monopulse RF sensor, installed on opposite side of the earth sensor, can be selected for yaw in combination with the earth sensor, sensing errors with respect to Kashima Main Transmit and Receive Station which is about 7° offset from the center of the earth when looked down from the spacecraft. Sensed attitude errors are processed in on-board CPU of the attitude control electronics so as to drive the actuators for restoring spacecraft attitude. As actuator, the spacecraft has a reaction wheel for each three axis. The spacecraft attitude is primarily maintained normal with these three reaction wheels. For both unloading of wheels and backing up for attitude control wheels, and also for station keeping maneuver are there installed two banks of thruster pair for each axis together with another redundant pair for east-west direction.

Station keeping and its results

Nominal station keeping

Table 2 shows nominal station keeping of the BSE. Around the orbit position of 110° E, earth triaxiality acts on the spacecraft making its orbital radius gradually larger, consequently drifting it westward. To keep the spacecraft's orbital position within required range of 110° E ±0.1°, east-west maneuver has been required nominally every three weeks. An east-west maneuver is performed with firing a pair of pitch thrusters for usually about 30 to 40 seconds continuously. East-west maneuver position has usually been set around 18:00 Local Sun Time to achieve proper eccentricity control at the same time. Regarding this point, some explanation will follow later. As to orbit inclination, lunisolar gravity increases it as time passes. To keep the orbit inclination within the requirement of 0.1°, north-south maneuver has been required usually about every two months. A north-south maneuver is performed with firing a pair of yaw thrusters for usually about 20 minutes continuously at either around ascending or descending node. North-south maneuver position could be selected at any suitable orbital time except between 2 hours before or after noon and midnight in Local Sun Time, because of rather large disturbance torque caused by thruster plume impingement on the solar panels without sufficient control capability in yaw.

Typical station keeping procedure

A typical station keeping procedure is shown in Figure 1. Before maneuver, ranging has to be done for 10 minutes every hour by two tracking and data acqui-

Table 2. Nominal station keeping of the BSE

	Requirement	Keeping cycle	Thruster fire duration on each maneuver	Maneuver position
East-west	110°E ±0.1°	Every 3 weeks	Approx. 30-40 sec continuous firing	18.00 (LST)
North-south	±0.1°	Every 2 months	Approx. 20 min. continuous firing	Any position except for noon ±2 Hrs. midnight ±2 Hrs
Eccentricity	(3×10^{-4})	* Achieved with east-west maneuver * Performed after north-south maneuver		

sition station in turn. Up to 8 hours of ranging is required to determine the orbit with acceptable accuracy. Right after acquisition of a pair of data, orbit determination and maneuver plan are succeedingly made. Following the plan, maneuver is performed followed by a set of another ranging and orbit determination. The differrence between E-W and N-S station keeping in procedure stems from thruster plume impingement on the solar panels during about 20 minutes long N-S maneuver which causes the spacecraft drifting eastward or westward and also affects its eccentricity. Consequently compensation of these affects is needed that makes the difference.

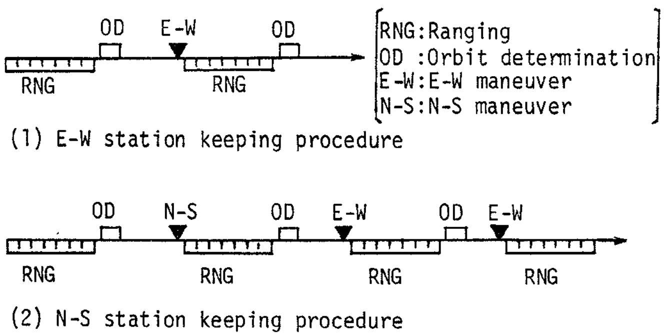


Figure 1. A typical station keeping procedure

Sun oriented eccentricity control

Since solar array panels having large area always receive much solar pressure, the spacecraft is decelerated during earlier half of its diurnal orbit and is accelerated during later half. This will result in causing eccentricity larger. In case of the BSE, eccentricity will grow up to 0.001 at maximum and daily longitudinal change to 0.115° in a half year. For accomplishing eccentricity control together with major axis control, "Sun Oriented Eccentricity Control" has been adopted. This method features setting E-W maneuver point of every 3 weeks around 18:00 Local Sun Time. The Sun Oriented Eccentricity Control has served in two ways, to simplify maneuver operation and to save fuel.

Orbit inclination history

The orbit inclination history of the BSE is shown in Figure 2. Inclination of the BSE has been kept within the required 0.1°

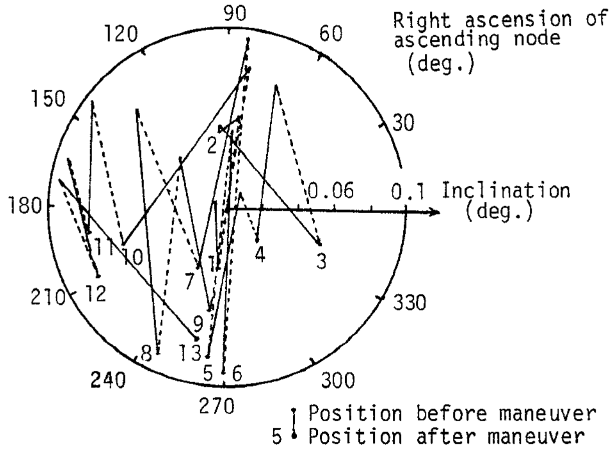


Figure 2. Orbit inclination history

Performance of the satellite attitude control

Features of attitude control

Figure 3 presents features of attitude control in orbit. The dominant disturbance torque acting on the BSE is the one by solar radiation pressure. The accumulative angular momentum by the disturbance is designed to be usually absorbed by the reaction wheels installed to each axis, keeping spacecraft attitude normal. The 2nd feature is the attitude control during thruster firing, which is in usual case, required for wheel unloading and for station keeping maneuver. Attitude controls in these cases are performed automatically onboard. Especially in station keeping maneuver where arises a rather large disturbance torque, sensor signals are sampled in every second instead of every 16 seconds in normal state, so as to get sufficient attitude control torque by thrusters. The 3rd is the feature specific to the BSE, that includes yaw control with sun sensor assembly and attutude control at wheel zero-crossing. Respective appearing time of these features observed are described on this figure.

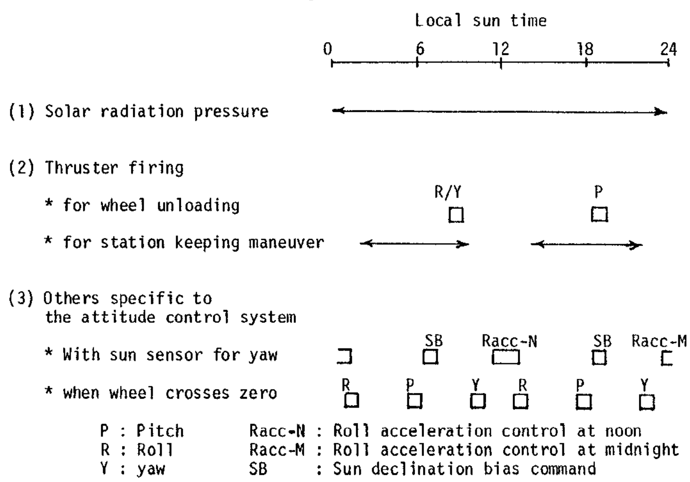
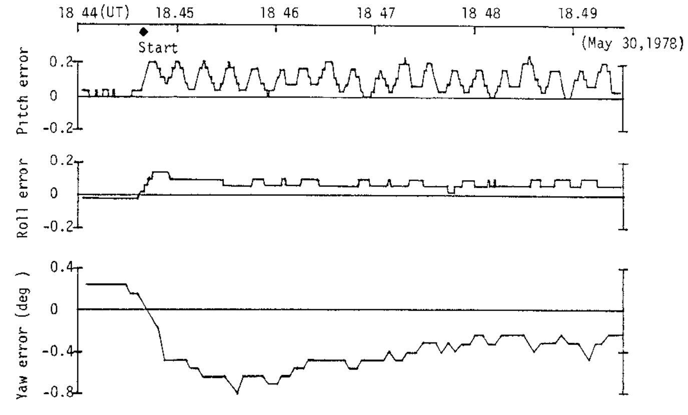


Figure 3. Features of attitude control in orbit

Attitude control capability during N-S maneuver

Figure 4 shows a typical attitude errors telemetered during N-S maneuver. Sensed attitude errors within ±0.2° for pitch and roll, and within ±0.8° for yaw are observed on the figure.

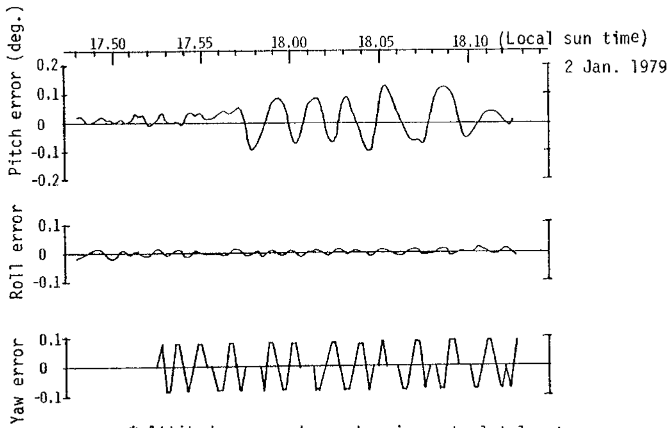


* Sensors (P.R.Y) as (ES.ES.SUN)

Figure 4. A typical attitude sensing errors during N-S maneuver

Attitude control around pitch wheel zero-crossing

Figure 5 is an example of a typical attitude errors telemetered during pitch wheel zero-crossing which is daily appearing around 06:00 and 18:00 Local Sun Time. Attitude errors during pitch wheel zero-crossing could be clearly recognized because of the least moment of inertia around pitch among 3 axes. Sensed attitude errors within $\pm 0.1°$ for pitch, roll and yaw are observed on the figure.



* Attitude errors by each axis control telemetry
* Sensors (P.R.Y) as (ES.ES.SUN)

Figure 5. A typical attitude errors around pitch wheel zero-crossing

Some specific operations with the BSE

Wheel unloading

A typical variation of the wheel momentum is shown in Figure 6, above for a week including winter solstice of 1978, below for a week including vernal equinox of 1979. Disturbance torque usually acting on the spacecraft by solar radiation pressure is the cause of the change of angular momentum of each axis. From this figure, less disturbance is recognized in spring than in winter. Since the capability is limited of absorbing accumulative angular momentum, wheel unloading is required when the wheel speed reaches its higher limit. Unloading is frequently, almost daily performed around both winter and summer solstice, but less frequently, approximately every 2 weeks around both vernal and autumnal equinox.(1)(2)

Operations with sun sensor for yaw

When sun sensor assembly is selected for yaw, such specific operations as sun declination bias command, roll acceleration command and solar array panel trimming are required.(1)(2)

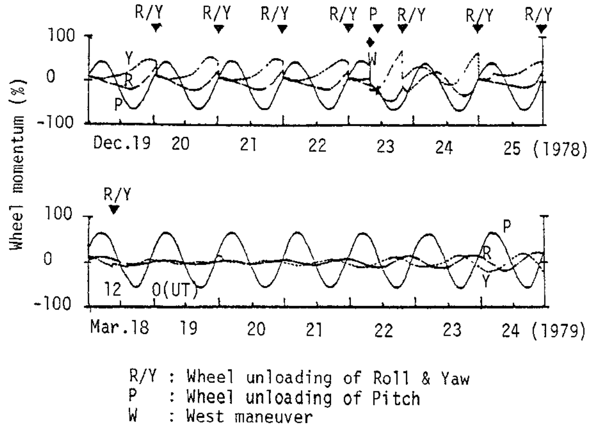


Figure 6. A typical variation of the wheel momentum in winter and spring

Eclipse operation

During the eclipse, TV transponders had to be turned off in order to keep the depth of the battery's discharge within its limited capability. Since the geostationary position of the BSE was designated about 25° westward in longitude from Japan, a normal eclipse due to the earth occurs centering around 01:40 Japan Standard Time. But an eclipse due to the moon might occur during the day time. So, early resume of broadcasting after eclipse has been requested. In case of the BSE, it took about 45 minutes after eclipse to restart broadcasting.

Conclusion

Sophisticated operational achievements on station keeping and house keeping including attitude control reached with the BSE were shown. Flight data evaluation and study are still ongoing in its 3rd year of mission. As a new project for an operational broadcasting satellite in Japan is to be started in 1980, these operational results are expected to provide practical information on designing convincing operational spacecraft.

Acknowledgement

The authors wish to acknowledge a favor to the engineering staffs of RRL and NHK as well as operating personnel of NASDA in preparation of this paper.

References

(1) T. Ishida, S. Soejima, Y. Ichikawa, "Present situation of Japanese Satellite Broadcasting for experimental Purpose", IEEE Transactions on Broadcasting, Vol. BC-25, No.4, Dec. 1979.

(2) Y. Ichikawa, "The results of Japanese Broadcasting Satellite for Experimental Purpose", IEEE Transactions on Broadcasting, Vol. BC-24, No.4, Dec. 1978.