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PRESENT SITUATION OF JAPANESE SATELLITE BROADCASTING FOR EXPERIMENTAL PURPOSE

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Abstract

Results of operations and experiments performed with the Japanese broadcasting satellite (BSE) are introduced. The BSE was launched in April 1978 for the purpose of technical evaluation of the 12 GHz satellite broadcasting system. One year long experience with the BSE proves the feasibility of direct television broadcasting from the satellite as well as the soundness of design and technology applied for the BSE.

This paper is intended to provide information about the BSE experiments to those who take a general interest in broadcasting satellite and some familiarity with space technology. Detailed presentation of the radio wave propagation and reception experiment performed with the BSE is left to another paper on this issue.

Introduction

The Japanese broadcasting satellite (BSE) was launched successfully from the United States Cape Canaveral Eastern Test Range on April 8, 1978. The BSE is a geostationary satellite with a three-axis attitude stabilization system and capable of transmitting two color TV signals at the rf power level of 100 watts in the 12 GHz band. After the initial check-up of the satellite performance by the National Space Development Agency of Japan (NASDA) on the geostationary orbit at 110°E, the technical experiments with the BSE have been started on July 20, 1978 by the Ministry of Posts and Telecommunications (MOPT) with the cooperation of the Japan Broadcasting Corporation (NHK). NASDA, however, is continuously responsible for the station keeping and the house keeping of the BSE. Accordingly, some important data related with the satellite technology will be contributed by NASDA in this paper.

Following the experiment plan developed by the BSE program committee, the fundamental technical performance of the BSE system, that is, coverage area, TV signal transmission characteristics, reception picture quality at various locations etc. are examined. The Main Transmit and Receive Station (MTRS) located at Kashima Branch of Radio Research Laboratories is the key station in the BSE program. Results obtained with the MTRS are summarised in the following section.

The MTRS provides not only TV signal transmission but also Tracking, Telemetry and Command operation. Every experiment starts with the initiation by the MTRS which sends a command to switch on the on-board transponder of the BSE. Meanwhile, the S-band TT&C operation is under the control of NASDA. MTRS and NASDA Tsukuba Space Center are tied with a data communication line to exchange the information concerned with the BSE as well as the CS and ECS which are also the experimental satellites promoted by MOPT. To facilitate the experiments, some of the satellite data are also sent to NHK Broadcasting Center through the line. NHK operates two Transportable Transmit and Receive Stations (TTRS), several Receive Only Stations (ROS) and a number of Simple Receive Equipments (SRE) scattered over throughout Japan. One of TTRS, a mobile one, has travelled along some 2000 miles visiting main cities from Hokkaido, northern part of Japan, to Kyushu, southern part of Japan and conducted TV transmission experiment at the NHK local TV stations.

It is well known that the radio wave propagation at the higher frequencies above 10 GHz suffers ocassionally an attenuation caused by rainfall and in some case, by wet snow. Since the BSE adopted 12 GHz band for its down link frequency, measurement of rainfall attenuation is considered as of great importance. At the MTRS, studies are made not only on the data of 12 GHz received field strength but also on cross-polarisation components, polarisation plane angle and their variation measured by the 13 meter dish antenna systems. Along with the MTRS at Kashima, a specially designed weather radar is installed to provide information about rainfall rate distribution along the radiowave propagation path from the BSE with spatial resolution of 250 meters x 1.5 degrees. For studies on statistics of rain attenuation in various locations in Japan, data obtained at every ROSs are collected daily through telephone line or the BSE in-hand talk-channel. Results of these studies may be referred to elsewhere on this issue of transaction.

Besides the above mentioned fundamental experiments, a number of experiments are going to be carried out to develop advanced TV broadcasting technique or new application of satellite broadcasting system. They are, for example, PCM-TV transmission, ranging system using TV synchronous signal and so on. Among them, standard time and frequency signal distirbution system via satellite and high definition TV transmission are described.

Measurement of fundamental transmission characteristics of broadcasting satellite links

Radio frequency transmission characteristics

To clarify the rf transmission characteristics of satellite transmission links, various characteristics have been measured at the main station. They are level diagram of satellite links, transmitting power and its variation in up and down links, C/N and S/N in up, down and overall links, frequency characteristics (amplitude, delay DG, DP), transponder input-output characteristics and frequency stability, spurious and intermodulation characteristics, and so on.

Here several representative characteristics will be described. Fig. 1 shows the frequency arrangement for the BSE TV transponder. Fig. 2 gives the block diagram of the TV transponder. As seen in Fig. 2, the receiving section consists of a primary and a redundant receivers and the transmitting section consists of ch A, ch B, and redundant (common to ch A and ch B) transmitters.

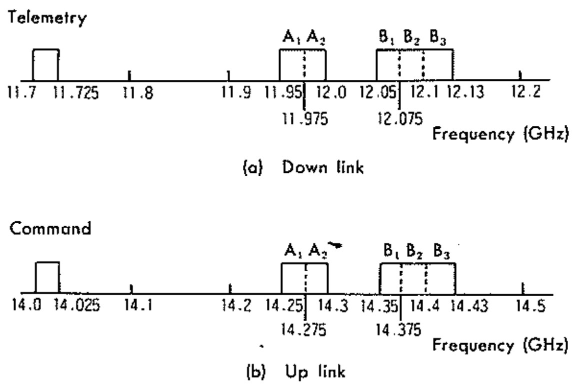

Fig. 1 Frequency arrangement for the TV transponder

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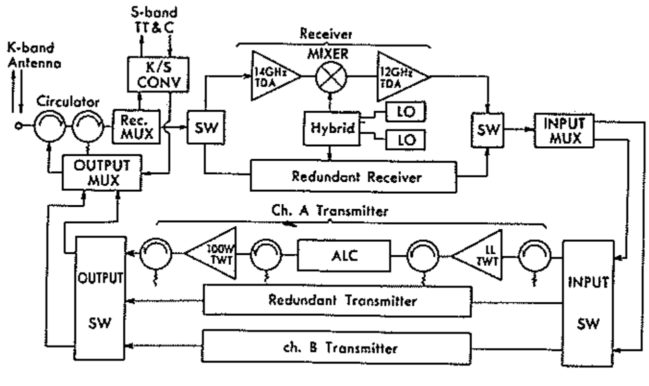


Fig. 2 Block diagram of the TV transponder

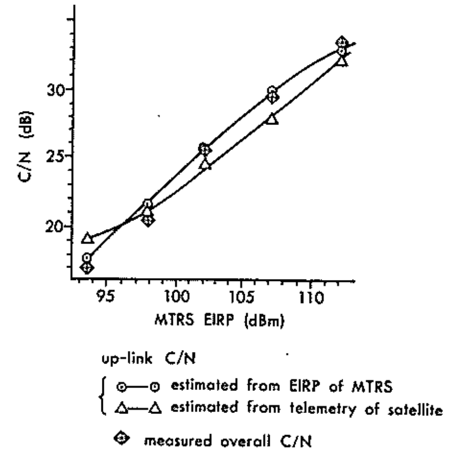


Fig. 3 C/N measurement result

(1) Level diagram of satellite links – As level diagrams are the most fundamental characteristics, they have been measured from the initial check period up to the present. Design values of the BSE link levels are given in Table 1.

Table 1 BSE link budget

		MTRS	Mainland	Remote islands
Up-link (MTRS to BSE)				
MTRS, E.I.R.P.	(dBm/ch)		112.2	
Free space loos	(dB)		-207.4	
Rx. antenna gain	(dB)		38.1	
Noise power	(dBm/25 MHz)		-92.9	
Up-link C/N	(dB)		35.8	
Down-link				
Service area		MTRS	Mainland	Remote islands
Antenna of Rx.	(m)	13.0	1.6	4.5
Tx. power	(dBm/ch)		50.0	
Tx. feeder loss	(dB)		-1.7	
Tx. antenna gain	(dB)	37.6	37.0	28.0
Free space loos	(dB)	-205.9	-205.8	-205.4
Rx antenna gain	(dB)	61.9	43.0	53.5
Rcved carrier power	(dBw)	-58.1	-77.5	-75.6
Noise power	(dBm/25 MHz)	-96.4	-97.3	-96.6
Down-link C/N	(dB)	38.3	19.8	21.0
Total C/N	(dB)	33.9	19.7	20.9
TV signal quality				
FM improvement factor	(dB)		18.6	
Emphasis improvement factor	(dB)		2.9	
Unweighted S/N	(dB)	55.4	41.2	42.4

Measured link levels coincide with designed values well within 2 to 3 dB.

(2) C/N, S/N and noise characteristics – At the main station, C/N is usually very high compared with other satellite links. So C/N can be measured over very wide range in the BSE links. The measurement was performed with modulation and demodulation parameters listed in Table 2. Fig. 3 gives measurement results of C/N in up and overall links. C/N in uplink can be estimated from EIRP of the main station, and also from telemetry data of the satellite. Both estimated C/N values coincide within tolerances of 1 to 2 dB corresponding to telemetry quantization errors. Measued values of S/N conincide fairly well with calculated curves, and improvement effect by emphasis (2.9 dB) is also apparent.

Table 2 Parameters in C/N and S/N measurements

Measured channel	A_1
Satellite transponder	Primary
Transmission bandwidth	25 MHz
Noise temp. of MTRS receiving system	660 K
Noise temp. of Satellite receiving system	1,500 K
FM frequency deviation	14 MHz p-p
Video signal bandwidth	4.2 MHz
Sound/video signal level ratio	1/6
Sound subcarrier frequency	4.5 MHz
Emphasis characteristics	CCIR Rec. 405-1

(3) Noise figure of transponder – Using LCE (Level Control Electronics) settings as parameters, C/N in up, down, and overall links were measured to get noise figures of transponder with varying EIRP of the main station. Fig. 4 gives noise figures for channel A1 transponder. The noise suppression effect caused by HL-TWT's (100W TWTA) nonlinearity is apparent.

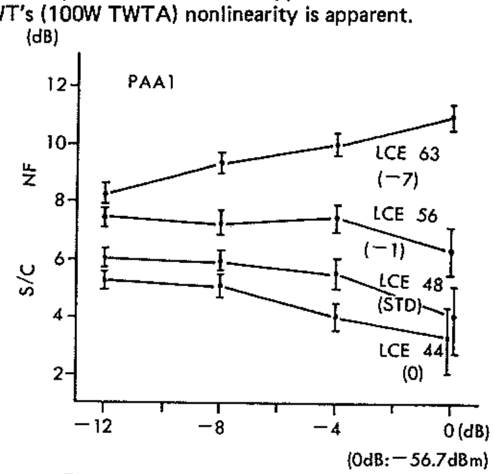


Fig. 4 NF characteristics of transponder

(4) Frequency characteristics (amplitude, delay, DG, DP) – It is fundamental to examine the frequency characteristics of amplitude, delay, differential gain (DG) and differential phase (DP) to know the satellite links characteristics for transmitting FM television signals.

In the satellite loop-back measurements, characteristics of both the satellite transponder and the earth station are mixedly measured. The characteristics of satellite transponder are obtained by subtracting the characteristics of earth station from the characteristics measured in satellite loop-back.

To transmit FM television signals faithfully, it is necessary to have flat amplitude and delay characteristics in pass-band. Fig. 5 shows measured amplitude and delay characteristics of overall link. Equalizers in the main station are effective in improving overall amplitude and delay characteristics. Fig. 5 gives the measurement results in March of 1979, showing little change from the characteristics measured in July of 1978.

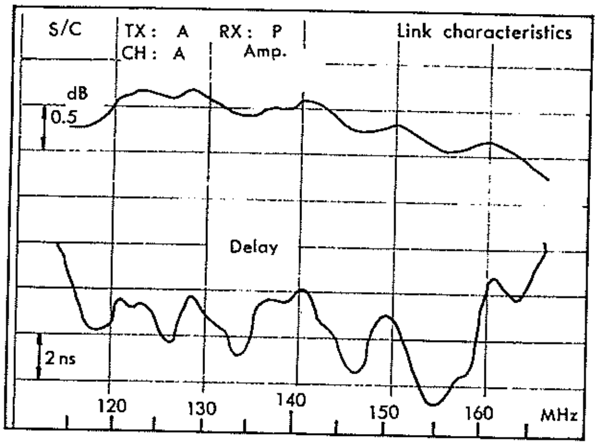


Fig. 5 Amplitude and delay characteristics of link

Fig. 6 shows DG and DP characteristics of overall link, which were measured at the same period as Fig. 5. It is seen from these measurement results that the BSE links have excellent RF transmission characteristics as television transmission links.

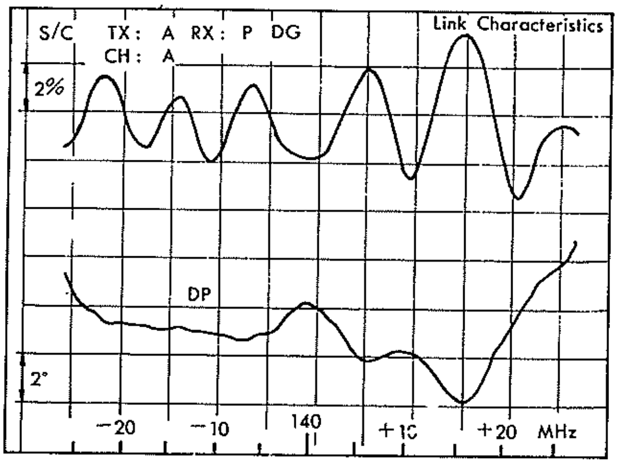


Fig. 6 DG and DP characteristics of link

Baseband transmission characteristics

Measurements of baseband transmission characteristics have been performed for many items. For video signals, they include modulation characteristics, amplitude and delay characteristics, waveform distortion, linearity (DG, DP), S/N and subjective assessment of picture quality. For sound signals, they are modulation characteristics, emphasis characteristics, frequency characteristics, distortion, S/N, and subjective assessment of sound quality, and so on. The BSE experiments have been conducted under the same parameter setting, assuming FM transmission of conventional NTSC-M color television signal as standard. Since January of 1979, dispersal signal has been added.

It is seen from these measurement results that baseband characteristics are almost determined by those of the main station, and are scarecely influenced by the satellite transponders.

Measurement of satellite on-board mission equipment characteristics

The on-board mission equipment consists of Ku-band antenna and communication equipments. To measure initial performance characteristics and time variation of them, the initial check and periodical checks per every half year have been performed.

As for the characteristics of transponder, following items were measured. They are input-output characteristics (linearity, AGC characteristics etc.), output characteristics (intermodulation, mutual modulation, spurious emission etc.), amplitude characteristics, delay characteristics, frequency stability, noise characteristics and so on. Among them, measurement results of amplitude, delay and noise characteristics are already described. Here results of several representative characteristics will be explained.

Transponder input-output characteristics

The transponders of BSE have LCE (Level Control Electronics) which operates to keep the output level of 100 W TWT constant. Fig. 7 shows the input-output characteristics of satellite transponders.

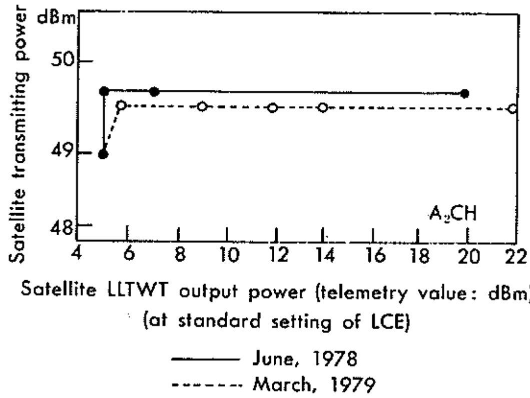


Fig. 7 Input-output characteristics of satellite

HL-TWTA (100 W TWTA) characteristics

Fig. 8 shows the input-output characteristics of 100 W TWT which can be measured by varying the settings of LCE. At the standard setting of LCE, 100 W TWT operates in saturating condition in order to obtain high efficiency.

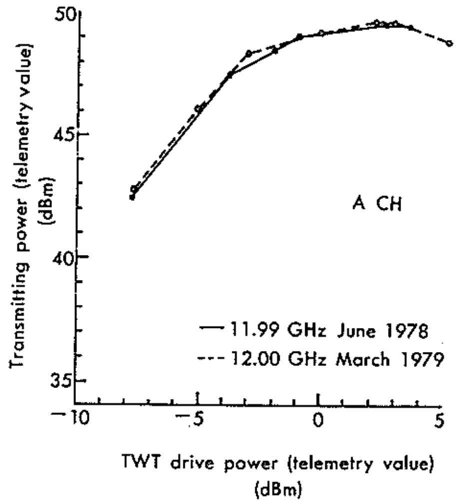


Fig. 8 Input-output characteristics of 100 W TWT

Variation of transponder output power

The output power level of satellite was obtained by converting the receiving level at the main station. As a whole, level variation of ±0.5 dB is observed during the period from July 1978 to March 1979.

Spacecraft configuration

Attitude Control System (ACS)

Attitude control system of the BSE is a three-axis zero momentum attitude control system. ACS functional block-diagram is shown in Fig. 9.

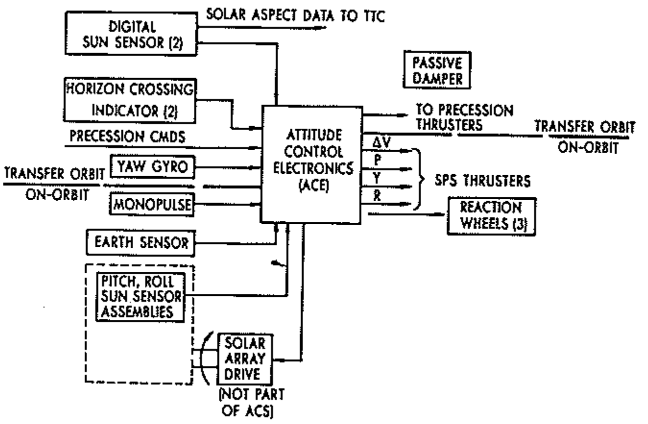


Fig. 9 ACS components by mission phase

BSE has three attitude sensors, static infrared Earth Sensor (ES) which detects roll and pitch error around the center of the earth, Monopulse rf sensor (MP), which detects roll and pitch error around the Main Transmit and Receive Station (MTRS) and Sun Sensor Assembly (SSA), which detects roll and pitch error around solar array panel.

A sensor combination which is used for spacecraft (S/C) normal operation is ES for roll and pitch attitude information source and SSA or Monopulse and Earth Sensor Combination (MECO) for yaw information source.

These sensors informations are processed by the Attitude Control Electronics (ACE). ACE drives independently each of required reaction wheels and keeps S/C attitude error within the requirement in normal operation (i.e. 12 GHz TV down link beam pointing error less than 0.2 degrees). And as required, one or more of 14 thrusters are fired by the ACE drive signal to perform wheel unloading and orbit control maneuver.

Secondary Propulsion Subsystem (SPS)

BSE secondary propulsion subsystem is monopropellant hydrazine system. Subsystem configuration is schematically illustrated in Fig. 10. These thrusters' configuration is functionally redundant composition. Two High Thrust Engines (HTE) are for precession control in transfer orbit, and residual 14 Low Thrust Engines (LTE) are used in drift orbit and on-orbit for initial acquisition and attitude and orbit control.

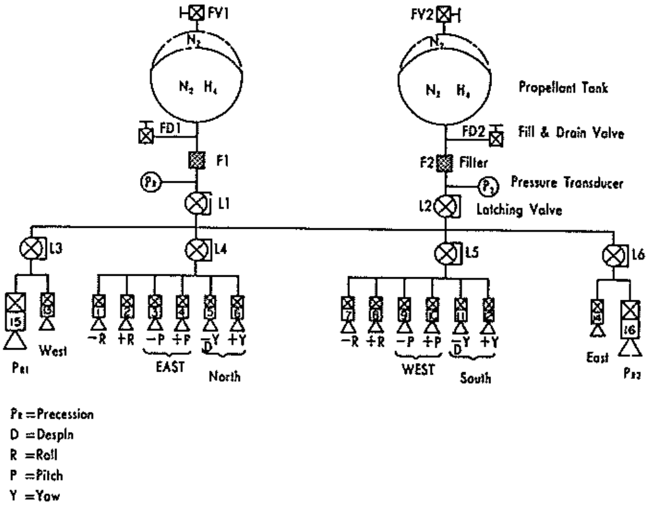


Fig. 10 Secondary propulsion subsystem block diagram

Attitude control operations

In order to keep the BSE 12 GHz TV down link beam pointing error within 0.2 degrees, routine operatins shown in Fig. 11 are needed. Details of these operations are explained in the following sections. These are carried out essentially on a daily basis except for solar array panel trimming.

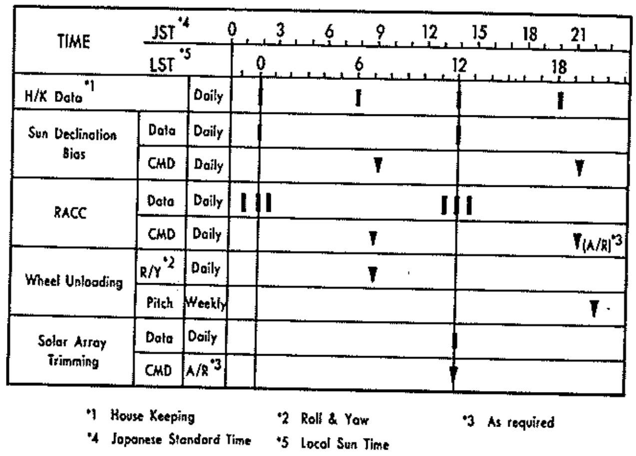


Fig. 11 BSE routine operations schedule

Wheel unloading

BSE has three reaction wheels which are independently controlled by the ACE (there is a partial relationship between roll and yaw wheels). The disturbance torque which works on BSE is mainly solar pressure torque. Reaction wheels are driven to eliminate S/C attitude error caused by solar pressure torque. But if wheel momentum exceeds ±80% of wheel capablility, the wheels cannot keep S/C attitude within required range.

So reaction wheel momentum dumping (unloading) is required to keep wheel momentum within ±80%.

Since pitch disturbance torque is almost cyclic, pitch wheel unloading has been performed on an weekly basis. But as for roll and yaw disturbance torque, since their wheel momentum grows as time passed, their wheel unloadings have been performed on a daily basis.

Roll Acceleration Command (RACC)

When the BSE is controlled by SSA for yaw control, SSA can not detect yaw attitude error near S/C local noon and midnight. In this region, yaw attitude is controlled by the RACC. This control method is an open loop control and the estimated roll disturbance torque which is calculated from the flight data of yaw attitude at exit of the RACC control to SSA control is used for yaw attitude control. Fig. 12 shows the RACC commanded value.

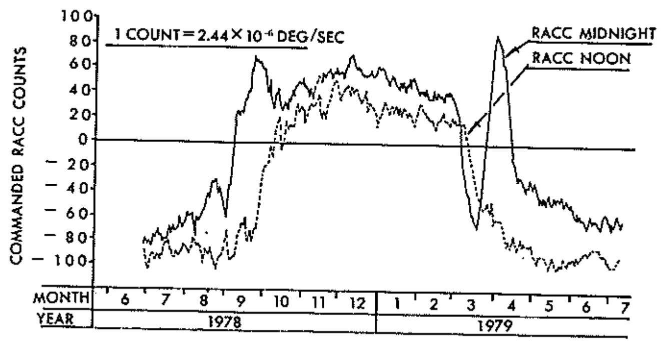


Fig. 12 RACC history

Sun declination bias

This sun declination bias command is also needed under the SSA control for yaw axis.

As the angle between the S/C orbit plane and sun-earth line changes by one year periods (±23.45°) ACE must be given a necessary declination angle by ground command.

Difference between the commanded sun declination bias and the true sun declination would be caused by the sensor temperature difference.

Solar array panel trimming

To generate efficiently electrical power, BSE Solar Array (S/A) panel always orients to the sun. But because of the elliptical orbit of the earth, S/A cannot orient to the sun correctly in all seasons. So solar array trimming has been performed by the ground command to keep its pointing error within ±1.0 degree.

Station keeping operations

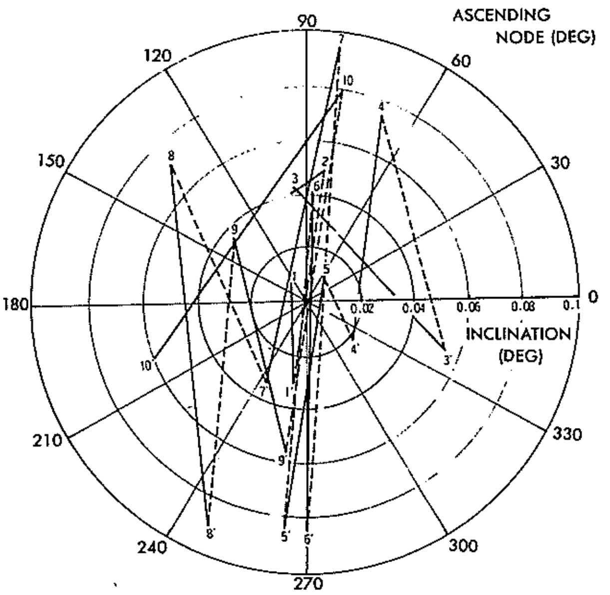
BSE nominal orbit position is 110° ±0.1° East Longitude and orbit inclination is less than 0.1 degrees. To satisfy the orbit positioning requirements, orbit maneuvers are periodically needed. Orbit control history and planning will be explained in the following sections.

North-south station keeping

Due to lunisolar gravity, BSE orbit inclination increases as time passes. To keep the orbit inclination within the requirement, north-south station keeping maneuver is required at ascending node or descending node with yaw pair thrusters continuous firing for about 20 minutes. All the inclination maneuvers have been successfully performed except for South ΔV on June 27, 1978. On June 27, 1978, temporary loss of the three-axis stabilization occurred because of the roll disturbance torque exceeding the control torque.

As the maneuver procedure was changed to adopt the larger control torque mode after June 27, 1978, following orbit inclination maneuvers have been successfully performed.

The orbit inclination history is shown in Fig. 13.



note) 1, 2, 3,……: BSE position before maneuver
1', 2', 3',….: BSE position after maneuver

Fig. 13 BSE orbit inclination history

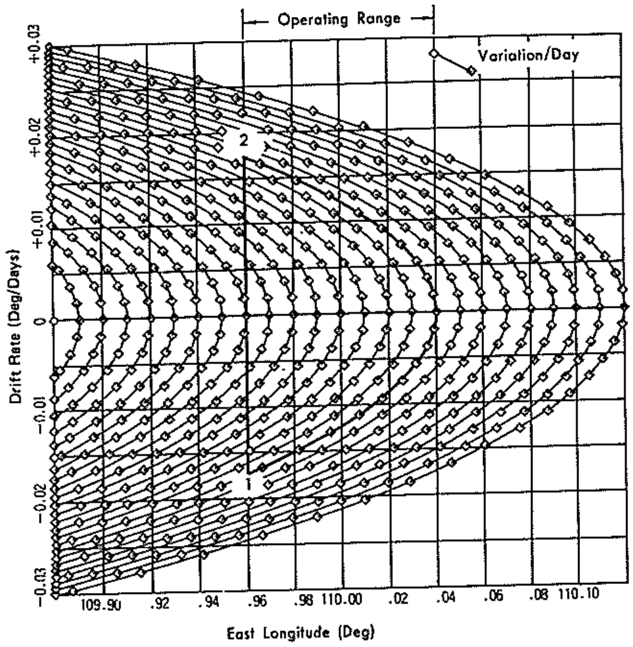
East-west station keeping

Because of the earth triaxiality, S/C is intending to move westwards and because of the large area of the BSE solar array, the eccentricity of the BSE orbit is more affected than other spacecraft by the solar pressure torque.

So BSE east-west maneuver cycle is more frequent than other spacecraft.

The BSE attitude is automatically controlled within the requirement by the attitude control thrusters during both N-S ΔV and E-W ΔV maneuver.

Fig. 14 shows east-west station keeping cycle pattern.



note) 1: BSE position before maneuver
2: BSE position after maneuver

Fig. 14 BSE E-W station keeping cycle pattern

Orbit keeping characteristics

The BSE satellite is automatically tracked by the main station, and azimuth and elevation angles of the tracking antenna are recorded automatically, Fig. 15 shows an example of the tracking antenna locus.

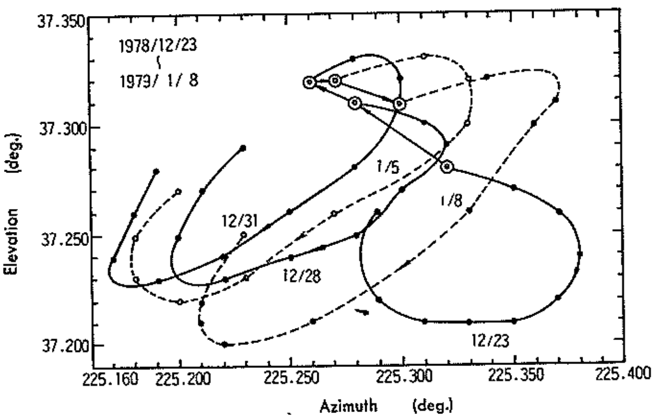


Fig. 15 Automatic tracking locus of AZ-EL

Graphs are drawn by connecting measured points at an interval of 2 hours from 2 to 20 o'clock every day, during the period of December 23, 1978 to January 1, 1979. It is known from Fig. 15 that after being chased eastwards by the east-west maneuvers, the BSE satellite began to drift westwards on December 31.

Further, the increase of deviating amplitude is noticed in the south-north direction, which is probably due to the increase of inclination angle with the equatorial plane.

The satellite moves in displaying repeated tracking locus like this during the period between contiguous east-west maneuvers.

The nominal orbital position for the BSE satellite is 110° E with allowance of ±0.1° for station keeping. It can be seen that the BSE orbital position is kept well within the specified value of ±0.1 degree.

Experiment on high-definition television transmission

Background

In spite of the highly matured state of technology present television standards NTSC, PAL or SECAM have reached, many people believe there still remain possibilities to attain a substantial improvement on television picture quality somewhere beyond the boundary of these present standards.

Since 1968, NHK has been engaged in the study on the high-definition wide screen television of which an interim report is adopted in C.C.I.R.[1] A high-definition television system parameter tentatively specified by NHK Technical Research Laboratories is shown in Table 3.

Table 3 Provisional standard of high-definition TV

Number of scanning lines	1125
Aspect ratio	3 : 5
Line interlace	2 : 1
Field repetition frequency	60 Hz
Video frequency bandwidth	
Luminance (Y) signal	20 MHz
Chrominance (C) signal	6.5 MHz*

* Line sequential

Needless to say, far wider frequency bandwidth is required for transmission of a high-definition TV as compared with the conventional TV, and no spectrum space below UHF is available for that purpose. Therefore, at the planning stage of the BSE project in which the SHF band is used, the experiment of the high-definition TV was recognized as of vital importance for its future development. This idea was reflected on the design of the on-board transponder, taking into account the requirement for wideband characteristics.

Experiment

Figure 16 shows the experimental system for the high-definition TV transmission with the BSE. A unique feature of this system is that the luminance (Y) and chrominance (C) signals are transmitted through the separate radio frequency channels. Necessary rf bandwidth is 80 MHz and 25 MHz for Y and C signals, respectively. Major advantage obtained by the Y/C separate transmission over the conventional composite colour signal transmission is a greater improvement, approximately 10 dB, of the signal to noise ratio. In other words, the satellite transmitting power can be decreased to 1/10 of that required for the conventional transmission method. For further details about the Y/C separate transmission, one may refer to the article written by Fujio[2].

For the uplink to the BSE, two 14 GHz transmitters equipped with the wideband FM modulators for the Y and C signals are prepared. The Y-channel transmitter is installed at NHK Tech. Res. Labs, while TTRS Type B is used for C-channel transmission. Transmitting antennas used are of 2.4 and 2.5 meters in diameter. On the satellite, taking advantage of the wideband characteristics of the on-board transponder, the received Y and C signals are commonly frequency converted from 14 GHz to 12 GHz and then amplified by the separate TWT to the power level of 100W, respectively.

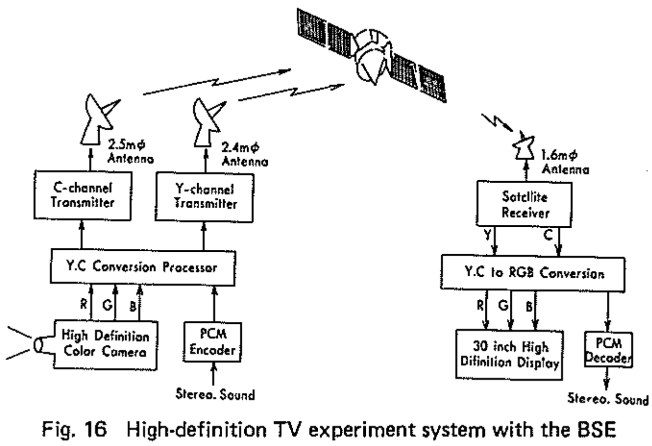


Fig. 16 High-definition TV experiment system with the BSE

To receive the high-definition TV signal from the BSE, an antenna of 2.4 meter in diameter with the low-noise converter is used. The rf Y and C signals are separated at the if stage of the receiver and then fed to each FM demodulator to recover Y and C baseband signals. The received picture is displayed on a 30 inch high-definition color CRT which was specially developed to assess the picture quality of the high-definition TV system.

Fig. 17 shows the 30 inch color monitor.

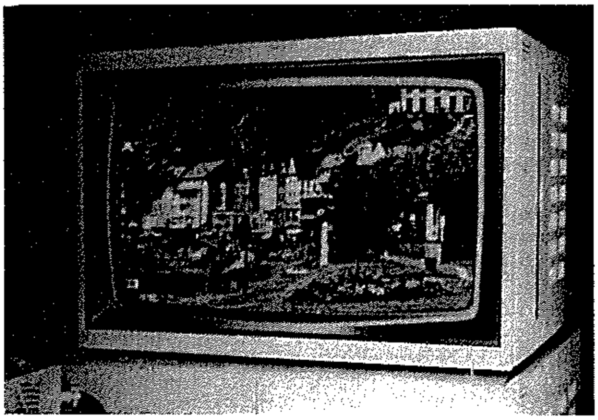


Fig. 17 30 inch color monitor for high-definition television

In November 1978, the first transmission experiment through the BSE was carried out at NHK Technical Research Laboratories for four days. As the signal sources, a color print of landscape scene and a strip from a 70 mm movie were picked up by the return beam Saticon camera and the special telecine equipment, respectively. Quality of the received picture was quite satisfactory so that one can hardly tell the degradation after the satellite transmission except a very slight increase of noise. Table 4 shows the carrier-to-noise ratio (CNR) measured on the Y and C channels. Also an average picture SNR is shown in Table 5. At the second transmission experiment held in March 1979, a high-definition TV reception was successfully demonstrated at the Ministry of Posts and Telecommunications down town in Tokyo.

Table 4 Carrier-to-noise ratio for Y and C channels

Date. (Nov. 1978) Time (hours)	8th 15:40	9th 10:00	13th 15:40	15th 15:40	Mean
CNR (dB)					
Y ch.	16.7	–	16.4	16.6	16.6
C ch.	21.7	21.2	23.2	22.7	22.2

Table 5 Picture signal-to-noise ratio for Y and C channels

	Y ch.	C ch.	Remarks
CNR (dB)	16.6	22.2	mean
SNR (dB)	40.6	49.2	unweighted

Remarks

The channel plan to be applied to the 12 GHz broadcasting satellite system operated in the ITU Regions 1 and 3 has been decided by the World Administrative Radio Conference held in 1977 (WARC-BS). Since the plan is based on the conventional TV system such as NTSC, PAL or SECAM, it is evident that the high-definition TV described here does not conform with the technical standards specified by the plan. From the technical point of view, however, the experiment still remains to be meaningful because the effectiveness of the Y/C separate trasmission method is proved through the actual satellite path, in considering its application to the 22 GHz and higher frequency bands allocated to the braodcasting service.

Preliminary experiment on the dissemination of time and frequency

Background

The dissemination of time and frequency standard by means of TV signals from a broadcasting satellite has a great advantage in the point that one can utilize such a system at any place throughout the country, using a simple receiving system with the same type of calibrating apparatus. But such system suffers from the frequency doppler shift due to the satellite orbital position variation. It is, therefore, necessary to take some preventive measures against this sort of frequency shift in order to disseminate the highly precise frequency standard.

This section gives an example of the results of a preliminary experiment made in the period from October 26 to November 2 in 1978, prior to the nationwide experiment by the BSE to be held in 1980.

First, the doppler shift of this kind was measured utilizing the color subcarrier in the TV signals from the BSE satellite, and the possibility of correcting the doppler shift by the prediction of orbital position was examined. Further, the short-term frequency stability of the received subcarrier was compared with that in terrestrial TV broadcasting.

Experiment

Fig. 18 shows a block diagram of doppler shift measurement system. Rb (rubidium) and Cs (cesium) atomic frequency standards were installed respectively at the BSE main station (at Kashima) and the RRL headquarters (at Koganei), about 100 Km apart each other. The two frequency standards are precisely synchronized in frequency to 1×10^{-12}, via TV synchronizing signals in the terrestrial TV signals. At both places the same type frequency synthesizers (HP5100A) are used to generate reference color subcarriers. At Koganei, a simple receiving equipment with 1 mϕ antenna was used, and received composite video signal was used to "GENLOCK" a sync-generator, of which 3.58 MHz output signal was used to measure the frequency doppler shift averaged over 10 minutes by way of reading the phase comparison record.

The BSE off-line software program was used to predict the frequency variation of received atomic frequency due to the doppler effects for the four places; Kashima, Koganei, Wakkanai and Okinawa.

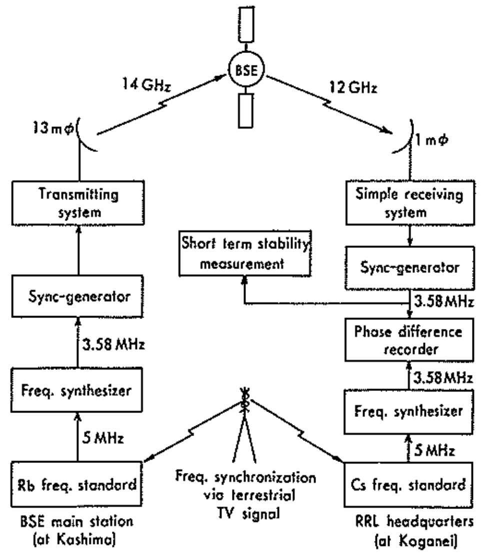
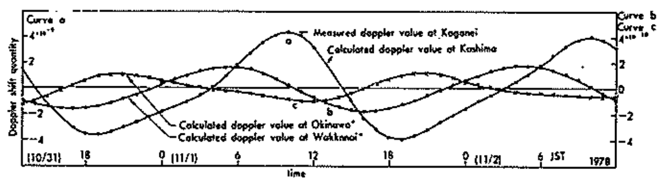


Fig. 18 Block digram of experimental system

The experimental result is shown in Fig. 19. Curve a gives measured doppler values at Koganei, together with calculated ones at Kashima which were estimated from predicted orbital values. Measured values coincide with calculated ones fairly well within the measurement error of 10^{-11} in the phase difference recording, although the dopplr shift amounts to $\pm 4 \times 10^{-9}$ which is comparatively large value due to the fact that the measurement period was just before BSE orbital correction maneuvers, and also just at a new moon time meaning much influence of heavenly bodies.



*: Calculated freq. shift when compensated at the transmitting side so as to cancel doppler shift at Koganei calculated by orbit determination program

Fig. 19 Doppler frequency by BSE

Curves b and c show respectively the values of doppler shift, relative to the value at Kashima, at Wakkanai and Okinawa, the farthermost locations in the country. These two curves show variation amplitudes of $\pm 2 \times 10^{-10}$. This means that it is possible to receive standard frequency with the error within 2×10^{-10}, everywhere in the country if some measures are taken to cancel the doppler shift as received in Tokyo area. That will be realized by the phase (frequency) control of the transmitter by use of the pre-correction of orbital prediction value or the servo control loop.

Further, it can be expected to get precision better than 10^{-11} by the method of averaging over 24 hours or utilizing zero doppler shift time calculated from orbital prediction value.

The measured values of short-term frequency stability of received color subcarrier from the BSE are shown in Fig. 20. For the averaging times within 10 seconds, the influence of doppler shift is hardly seen. The figure shows that it is possible to receive precise frequency information with almost same stability as in the terrestrial TV broadcasting.

As for the influence of transmission path, there was little influence on the phase comparison even in the hard rain time. So it is thought that 12 and 14 GHz propagation characteristics do not give any severe influence on the time and frequency dissemination.

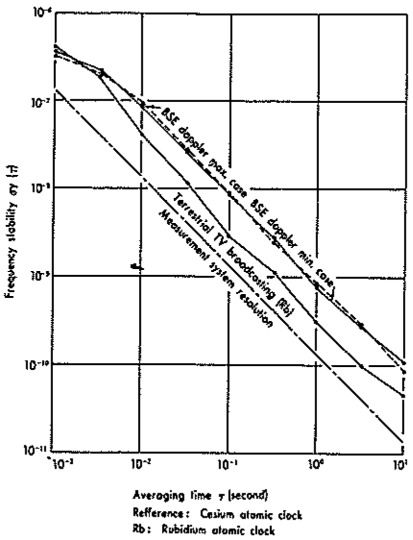


Fig. 20 Short-term stability of received subcarrier

Conclusion

The BSE program was initiated by MOPT in 1972 with the purpose of a study and technical evaluation of the 12 GHz satellite broadcasting system. Through the operations and experiments for the first year with the BSE, many useful results which will contribute to establish technical basis for future operational system have been obtained. Most of data show good agreement with pre-launch test data as well as predicted performance of the system. Studies of further applications of the BSE will be continued for another two years.

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References

1. C.C.I.R. Rep. 801, "The present state of high-definition television", XIVth Plenary Assembly, 1978.

2. T. Fujio, "A study of high-definition TV system in the future", IEEE Transaction on Broadcasting, Vol. BC-24, No. 4, Dec. 1978.

3. K. Tsukamoto, N. Imai, O. Ogawa and S. Tamai, "Technical aspects of Japanese Broadcasting Sattellite experiment", IEEE. Transaction on Broadcasting, Vol. BC-24, No. 4, Dec. 1978.