Overview of the Mobile Satellite Communication Experiments using the Engineering Test Satellite VIII

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The mobile satellite communications experiments using the Engineering Test Satellite VIII, which was launched in December 2006, have been conducted during about six years. The performance evaluation tests for onboard equipments, earth stations and mobile satellite communication systems carried out, and application experiments were also conducted. In this paper, the overview of the mobile satellite communications experiments as well as onboard equipments and earth stations are described.

1 Introduction

The Engineering Test Satellite VIII (ETS-VIII, nickname: KIKU No.8) was launched by H-IIA rocket on December 18, 2006. This is a 3-ton class large geostationary satellite. One of the objectives of the development of this satellite is the verification of the next generation mobile satellite communication system in space. Initial performance confirmation tests which lasted for about three months were carried out after launching. Following this, in the "Stationary Stage", "Basic Satellite Communication Experiments" consisted primarily of performance confirmation tests of satellite mounted equipment in orbit and mobile satellite communication system experiments conducted by satellite development organization (National Institute of Information and Communications Technology (NICT), Japan Aerospace Exploration Agency (JAXA), and Nippon Telegraph and Telephone Corporation (NTT)), and "Satellite Application Experiments" conducted by various institutions authorized by public offering by the Ministry of Internal Affairs and Communications were carried out for about 3 years. After the stationary stage was completed, "Second Stage" started where application experiments and periodical satellite performance confirmation tests were performed, and in December 2012, mobile satellite communication experiments by NICT were completed. This paper covers the outline of satellite mounted equipment used in the experiments, earth station and of mobile satellite communication experiments performed by the end of 2012.

2 Outline of satellite mounted equipment for communication experiments[1]

Communication signals pass through the ETS-VIII in each of the communication experiments. Therefore, this section covers only the outline of equipment for communication experiments mounted on ETS-VIII. Further, the outline of each earth station used in the experiment will be included in the description of each communication experiment shown in Section **3**.

Components constituting the communication mission equipment in the ETS-VIII to be used for mobile satellite communication experiments are feeder link equipment, onboard switches, transponder, large deployable antenna feeder and large deployable antenna reflector. Table 1 shows principal particulars of the communication mission and Figure 1 shows composition of the communication mission equipment. Onboard switches are divided into packet switch (PKT) with packet switching capability and onboard processor (OBP) with circuit-switched capability. The transponder which performs frequency conversion for mobile link using S-band frequency consists of up-converters (S-TX1, 2, 3) and down-converters (S-RX1, 2, 3)

Table 1 Major specifications of ETS-VIII

Orbit:	Geostationary orbit, 146 degrees East
Frequency:	S-band (2.6 / 2.5 GHz) for mobile link
	Ka-band (30 / 20 GHz) for feeder link
Antenna:	13 m mesh deployable reflectors for mobile link
	0.8 m offset parabola for feeder link
Tx power:	400 W for S-band
	8 W for Ka-band
Onboard switch:	Circuit switch for personal communications
	Packet switch for mobile communications

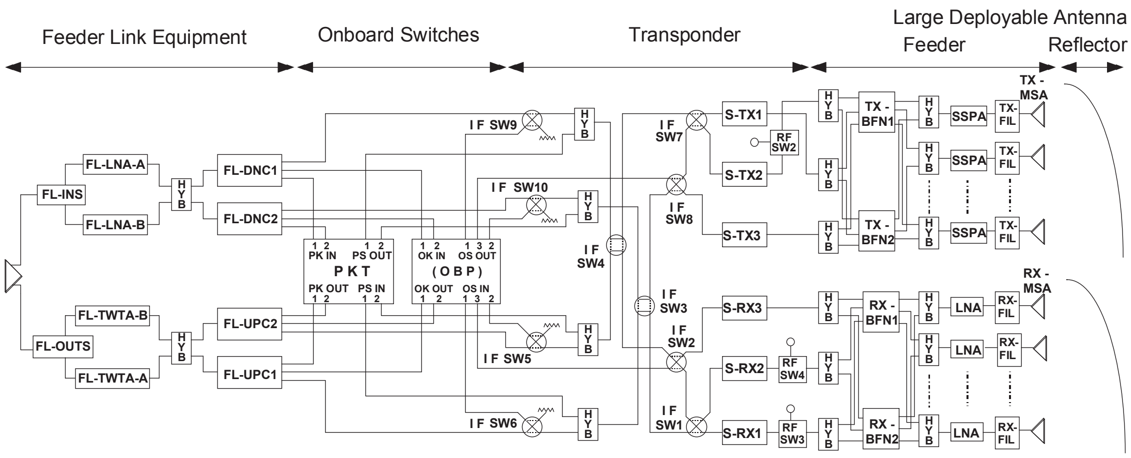

Fig. 1 Block diagram of ETS-VIII

for handling as much as 3-beams, and 10 intermediate frequency (IF) change-over switches (IF SW1 ~ 10). Switches are changed-over by the transponder depending on the packet switch and onboard processor used, and switching to bent pipe mode in which frequency conversion is solely performed for the same experiment and applied communication experiment is possible.

To the ETS-VIII is mounted a large deployable antenna having 13 m class electrical diameter size and phased array method is used for antenna feeder. The feeder unit consists of two types of beam forming networks (BFN), each 31 units of solid-state high power amplifier (SSPA), low-noise amplifier (LNA) and transmission and receiving antenna elements. A total of about 400 W high power is realized by 8 sets of class 20 W SSPA and 23 sets of class 10 W SSPA. A cup microstrip antenna (cup MSA) is used for the antenna elements to attain a light-weight and high-rigidity structure to realize a lower bonding amount between continuous elements. As for the BFN device, two types of uniform pointing control (BFN1) and independent pointing controls (BFN2) are mounted, while development of the device is carried out by NICT and NTT, respectively. With uniform pointing control BFN, common terms of excitation amplitude and phase necessary for formation of plural number of beams are controlled collectively and directional error caused by heat generated by the onboard equipment and by electrical factors could be corrected with ease. With independent pointing control BFN, each beam could be controlled freely from the earth station by controlling the directional pattern of each beam and deployment to the adaptive antenna system and the like is expected. Ka-band is used for feeder link for communication with the base earth station and high power amplifier of the satellite is a travelling wave tube amplifier (TWTA) with 8 W output. Meanwhile, the base earth station for feeder link is provided in Kashima Space Technology Center. Further, for backup of mobile link, radio-frequency (RF) system of high-accuracy time reference (HAC) (transmission and receiving antennas, high power amplifier and low-noise amplifier) is configured to be used and connection is possible by switching No.2 and No.4 RF switches (RF SW 2, 4) of the transponder.

3 Mobile communication experiments[2]

As for mobile satellite communication experiments, “Basic communication experiments” by the satellite development organization NICT, JAXA and NTT and “Satellite Application Experiments” by each of institutions authorized by public offering by Ministry of Internal Affairs and Communications were conducted in “Stationary Stage” for about 3 years. Basic communication experiments consist primarily of performance confirmation test of satellite mounted equipment in orbit and mobile communication system experiment which, after completion of the stationary stage, proceeded to “Second Stage” where application experiments and periodical satellite performance confirmation tests are performed. In December 2012, mobile satellite communication experiments by NICT were completed. The following description deals with the outline of each of experimental items.

3.1 Satellite mounted equipment evaluation test

a. Large deployable antenna characteristics evaluation experiments[3][4]

In the mobile satellite link using S-band for mobile satellite communication experiments, five beam patterns (Tohoku, Kanto, Tokai, Shikoku, and Kyushu beam) are made available as default antenna pattern. In the experiment, maximum three beams could be used simultaneously. Since the antenna is a phased-array antenna, arbitrary beams could be configured by changing the amplitude and phase value of BFN.

a-1 Measurement of antenna pattern

In the pattern measurement which is one of the basic characteristics of the antenna, attitude scanning of the satellite and received power at multiple points on the ground are measured at the same time to acquire two-dimensional patterns. In the measurement of transmission pattern, a signal is output by the satellite mounted switch and this radio wave is received on the ground.

a-2 Evaluation of antenna beam directivity variation

To evaluate beam directivity of the antenna by influences such as thermal strain of deployable antenna reflector, signal power from multiple antennas are measured continuously. Using results of this evaluation, antenna beam directivity variation is corrected by beam forming network to confirm effectiveness in orbit.

a-3 Beam scanning pattern measurement

Amplitude and phase value of BFN are changed for scanning of the antenna beam to take measurement of antenna gain with regard to beam scanning angle to acquire so-called beam scanning pattern for evaluation.

a-4 Evaluation of feeder unit excitation error

Amplitude and phase of BFN are set to form a beam to be measured and reference beam. Phase of the element is turned by applying REV method (Rotating Element Electric Field Vector Method) to array weight of the beam being measured and received power with regard to phase rotating angle is measured. Amplitude and phase of each element are calculated using measurement results and excitation error is evaluated.

b. Characteristics evaluation experiments for satellite mounted switches[5][6]

The ETS-VIII is mounted with onboard processor having circuit switching function and packet switch having packet switching function. Evaluation methods of switching functions include many common items, therefore this subsection deals with evaluations of satellite mounted switch performance collectively.

b-1 Basic transmission characteristics evaluation

Bit error rate characteristics, synchronous acquisition characteristics and others which are basic characteristics of the digital transmission device are acquired. Characteristics of the modulator and demodulator used for regenerative repeating are acquired in uplink and downlink of the satellite, respectively to check performances of the modulator and demodulator. Basic characteristics are also acquired in through repeater mode for comparison of performances with the case where the onboard switch is passed through.

b-2 Switching characteristics evaluation

A signal including control information is output from the earth station and it is checked if satellite mounted switch performs switching operation in accordance with the control information. In addition, time needed for switching control that is a basic parameter of switching function is measured.

b-3 Evaluation of switching program loading function

The onboard processor and packet switch mounted on ETS-VIII are designed to be capable of loading switching control program from the ground so as to correspond to switching control by means of various protocols. Any data that caused error during transmission is resent automatically to eliminate any error in the program. In the evaluation of switching program loading functions, it is checked if the program was loaded to the satellite without causing any error and at the same time, time required for program loading is measured and performance evaluation of automatic resending is also conducted.

b-4 Confirmation of location registration functions

With satellite mounted switch, switching control corresponding to multiple beam is performed in such that the mobile earth station recognizes and controls existing beams, while the base station receives control data from the onboard switch to confirm registration location of the mobile earth station.

c. High power transponder performance evaluation experiments[7]

As for characteristics evaluation as the transponder, measurements are taken at initial stage through in orbit characteristics evaluation experiments for onboard equipment and after that, similar measurements are taken periodically (yearly) to obtain secular change for evaluation. Items to be measured as the basic characteristics of the transponder include input/output characteristics, amplitude-frequency characteristics, intermodulation characteristics and the like. In the measurement, characteristics of mobile link side onboard equipment using primarily S-band are obtained and characteristics including the feeder link component are also obtained.

3.2 Mobile satellite communication system experiments

a. Switching system communication experiments[8][9]

In the communication experiments using onboard processor, packet switch, and corresponding earth station, transmission characteristics such as voice, data, and images are acquired for evaluation as the communication system. For each performance, data is acquired for a case where the earth station is in static condition and a case where it is in mobile environments by running a measurement vehicle. The ETS-VIII is a multiple beam satellite in the communication system. Therefore, location registration update tests when a mobile earth station is moved from one beam to an adjacent beam, frequency reuse experiment using the same frequency in different beams, and a connection experiment from the satellite communication system to other communication network are carried out.

b. Code modulation technology experiments[10]

As image transmission means to be used in the mobile satellite communication, we developed a mobile earth station using the modulator and demodulator based on MBCM (Multiple Block Coded Modulation). Multiplicity of multiple block code modulation could be changed-over by three switches of 2, 4, and 6. Further, shifting to another standard modulation method is possible to allow comparative experiments. Image codec employs MPEG4 format and unequal error protection function is available by which protection (3 steps) is provided depending on the importance of the data to be transmitted. Radio frequency part of the mobile earth station is of EIRP (Equivalent Isotropically Radiated Power) which is about 20 dBW, figure of merit (G/T) is about -15 dBK, and an antenna based on phased-array method is used at antenna unit of the earth station[11]. In the communication experiments, bit error rate characteristics which are basic characteristics of the digital modulator and demodulator are obtained, communication experiments under mobile environments are performed using a measurement vehicle carrying the earth station, and this modulation method in the mobile satellite communication system is evaluated. Meanwhile, no regenerative transponder of this method is provided to the satellite side and therefore, experiments of the satellite are performed under bent pipe mode.

c. Evaluation experiments of multicast communication system[12]

The multicast communication earth station was developed by Advanced Space Communication Research Laboratory (ASC) aiming at S-band mobile satellite digital voice transmission in which high-quality audio program of compact disc (CD) class is assumed. The station uses orthogonal frequency division multiplexing (OFDM) method for the multiplexing method and OFDM method is in compliance with 774 System-A recommended by ITU-R. Information rate is maximum 256 kbps per channel.

When OFDM method is used in the satellite system, although influences of nonlinearity in the amplifier poses a problem, in the system using the ETS-VIII, signal transmission is performed at the operating point close to the linear region of the high power amplifier, and ground test confirmed that degradation of transmission performance is negligible. In the demonstration experiments using a satellite, influences of nonlinearity in the high power amplifier and influences of the signal upon multiple path under mobile environments are verified primarily.

d. Earth station evaluation experiments[13]

d-1 Base earth station evaluation experiments

The base earth station provided in Kashima Space Technology Center includes Ka-band feeder link earth station and S-band reference earth station.

The feeder link earth station in Ka-band plays an important role in the experiments, while Cassegrain antenna having 5 m diameter is used for the antenna and TWTA with saturation power of 100 W is used for the high-output amplifier. Although basic performances were already obtained prior to satellite launching, important characteristics to be obtained after satellite launching include evaluation of satellite tracking characteristics of the antenna, and evaluation of automatic frequency control performance. For tracking of the satellite, automatic tracking function by means of step tracking and manual tracking function are provided. Frequency control is to correct frequency fluctuation attributable to the stability of the oscillator on the satellite, while control is made by receiving a beacon signal transmitted from the satellite. These characteristics could be evaluated by receiving radio waves from the satellite.

S-band reference earth station is a facility used as the reference station of mobile link in the mobile satellite communication experiments, and basic performances of this were already obtained prior to satellite launching. The antenna is a parabola antenna with 3.6 m diameter and a SSPA with saturated output of 20 W is used for the high power amplifier. This earth station fulfills a role of the monitoring station in the experiment and at the same time, is used for demonstration experiments of frequency control function compensating for frequency fluctuation of received signal due to movement of the satellite.

d-2 Evaluation experiments of portable type mobile earth station

Practical specifications of the portable type mobile earth station such as profile, weight and transmission power similar to those of cellular phone were investigated and a prototype was trial manufactured on the assumption that a large deployable antenna mounted on the satellite should be used. To attain miniaturization, the design is such that transmission and receiving antennas are installed into the upper portion of the earth station and exterior is free from protrusions. The built-in antenna is a ceramic patch antenna with gain of about 3 dBi and size of the element is 30 mm × 27 mm. Transmission power is about 1 W, and driving by battery is possible, and continuous talking more than 30 minutes is possible using AA cell batteries. Binary phase shift keying (BPSK) method is applied to the modulation method, transmission rate is 8 kbps, weight and volume excluding the battery are 266 g and 244 cc, respectively, which proves excellent portability.

4 Communication application experiments[14][15]

a. Antenna pattern correction experiments

With large deployable antenna which has multiple beams, based on a phased-array method and is designed to be mounted on the satellite, beam directivity varies due to excitation distribution error of the feeder unit and shape error of the reflector. Satellite-Terrestrial Integrated Mobile Communication System (STICS) currently investigated assumes development of a satellite mounted antenna having large reflector of 30 m class diameter. For correction of these errors, we developed “Large antenna directivity fluctuation simulation software”. In the experiments, rotation angle of the reflector is assumed using the software based on the data obtained by REV method using plural number of earth stations and effectiveness of the software developed is verified.

b. Low side lobe experiments

Characteristics evaluation of the large deployable antenna was made in the basic experiments and it was confirmed from excitation distribution error of the feeder unit and shape error of the reflector that the side lobe level exceeded the design value. For this reason, the software developed based on the data obtained by REV method using plural number of earth stations was modified, functions were added, and profile of the reflector was assumed. Experiments to lower side lobe were then performed. In this application experiments, effectiveness and adequacy of reflector profile estimation technology and excitation distribution estimation technology in orbit were verified.

c. Data transmission experiments using aircraft

A mobile earth station is mounted on the aircraft and applicability of S-band frequency to aeronautical mobile satellite communication is verified. Low profile active phased-array antennas developed to be mounted on vehicles are used for the antenna of the aircraft earth station and mounted to the upper part of the airframe. Modulators and demodulators available on the market are used. In the experiment, packet signal is transmitted from the aircraft, received by the earth station via satellite link and received signal level and error rate of the packet are obtained. Data are obtained at level flight of the aircraft, turning flight and static condition (landed), and comparative evaluation is made.

d. Sensor network experiments

For the sake of detection of disaster occurrence and earlier detection of it, we have been investigating satellite sensor networks capable of collecting necessary information even from areas where communication means and power supplying are hardly available. In this experiment, data transmission is made between sensor experiment earth station and base station on the earth to acquire characteristics. Automatic data collection and prolonged operation are required for sensor experiment earth station and therefore, output power for communication is suppressed to 0.8 W, signal transmission is made intermittently, and transmission interval could be controlled from the base earth station. Further, transmission possible information rate is 50 bps and spreading code by direct spread spectrum is applied to communication signals to allow for stable demodulation at lower rate. Small-sized helical antenna which could be installed easily on the mobile object is used, and directivity of this antenna is omnidirectional in azimuth direction and half gain width is about 40° in elevation angle direction. In the experiment, frame error rate (FER) that is basic characteristics is obtained, the earth station is mounted on a buoy on the sea surface, and effectiveness of detection of seismic surges is verified.

5 Conclusions

Outline of mobile satellite communication experiments using ETS-VIII is introduced. Development of ETS-VIII was started in 1992 and the satellite was launched eventually in 2006 after delayed significantly due to delay of H-IIA rocket development. As for the communication equipment, although the receiving system of the large deployable antenna caused a trouble and the experiments were interrupted temporarily, original targets established before the launching were almost accomplished thanks to efforts of the people concerned. Experiments conducted by NICT were completed in December 2012, while the satellite is still utilized as of February 2014. The authors hope that results obtained in the experiments will be some help to develop future mobile satellite communication systems.

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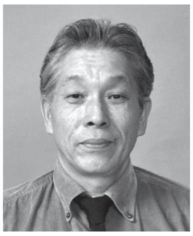

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