Aeronautical Mobile Satellite Data Communication Experiments

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The Engineering Test Satellite VIII has onboard equipments for the mobile satellite communications system using S-band frequency. The data transmission test for the aeronautical mobile satellite communication was carried out using the Engineering Test Satellite VIII. The test results showed that the throughput performance in the case of the level flight was almost as same as that in the case of the static condition, and that in the case of the 20 degrees turning flight was about 2 dB less than that in the case of the static condition.

1 Introduction

Engineering Test Satellite VIII (ETS-VIII, Kiku No.8) is a large geostationary satellite (weight: 3 tons) launched by an H-IIA rocket in December, 2006[1]. S-band (2.6/2.5GHz) communication devices are mounted in the satellite. The performance of components mounted on the satellite was evaluated and land mobile satellite communication experiments were performed by these devices[2]-[4]. This time, the authors had a chance to perform an aeronautical satellite communication experiment. In this experiment, the earth's surface was imaged with a synthetic aperture radar from an aircraft, data were transmitted to the earth station via satellite, the image data were successfully transmitted to the earth station at approximately 100 kbps, a transmission test by packet signal was executed in order to obtain basic performance information in transmission during flight and data such as throughput rate and receiving power were obtained. This paper gives an outline of the aeronautical satellite communication system used in the experiment, and describes the results of the transmission experiment performed.

2 The aeronautical satellite communication system

The aircraft used in this experiment was a Gulfstream II. A flat type active phased array antenna (APAA) developed for vehicle was used[6] for the antenna of the aeronautical earth station. The antenna was mounted on the top of the aircraft. The antenna radome used in the Ka-band mobile satellite communication experiment[7] performed in the past was used for this test. A synthetic aperture radar for imaging is mounted below the aircraft. Figure 1 shows the configuration of the experiment system. The base station was built at the Kashima Space Technology Center. An S-band base station having a parabolic antenna of 3.6m in diameter was used. Table 1 shows the specifications of the aeronautical earth station. The modem is a commercial item and has BPSK, QPSK and Offset QPSK as modulation methods. The transmission speed can be adjusted from 5 kbps to 3 Mbps.

A fault was found in the large deployable antenna receiving system[8] of the ETS-VIII in the initial performance test performed after launching. A parabolic antenna with an aperture of 1m in diameter for positioning experiment was used for receiving the S-band uplink in the communication test. The figure of merit (G/T) of the receiving system is approximately -6 dBK. That is approximately 20 dB lower than the G/T that the large deployable antenna is supposed to have (approximately 14 dBK). The S-band was used for up-link and down-link. A bent-pipe mode was set to the satellite. Table 2 shows an example of link budget in the case of level flight. As shown in Table 2, the communication quality of the down-link is high enough. Communication quality is decided by the up-link signal which is transmitted from the aeronautical earth station to the satellite. The standard signal power vs. noise power density ratio (C/No) that can be set to the satellite link is approximately 56 dBHz.

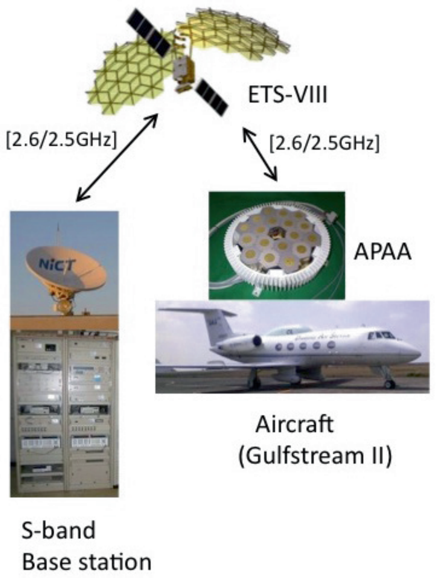

Fig. 1 System diagram for aeronautical satellite communication experiment

Table 1 Major specification of aeronautical earth station

Antenna Unit
- Frequency:
  - Tx: 2655.5 - 2658.0 MHz, Rx: 2500.5 - 2503.0 MHz
- Gain: Tx: 12.3 dBi, Rx: 14.5 dBi
- Radiating element: Two-layer self-diplexing antenna
  - Upper layer: Circular patch (Tx)
  - Lower layer: Ring patch (Rx)
- Number of elements: 18
- Phase shifter: Endless analog phase shifter
- EIRP: 26.3 dBW G/T: -12.3 dBK
- Polarization: Left hand side circular polarization
- Size: 440 mm (Diameter) × 117 mm (Height)
- Weight : 18.7 kg Power consumption: 354 W
- Tracking method: Closed loop, Open loop
- Tracking speed: 30 degree/sec (max)

Modem Unit
- Modulation: BPSK, QPSK, Offset QPSK
- Transmission Rate: 5 kbps - 3 Mbps
- Error correction: Convolutional code, Reed-Solomon code, Turbo code

Table 2 An example of link budget of return link

Up-link (2.6 GHz)		Down-link (2.5 GHz)	
Aeronautical earth station		Satellite	
HPA output power	25.0 W	HPA output power	20.0 W
Feed loss	0.0 dB	Feed loss	1.8 dB
Antenna gain	12.3 dBi	Antenna gain	40.8 dBi
Mobile station EIRP	26.3 dBW	Satellite EIRP	52.0 dBW
Propagation loss	192.8 dB	Propagation loss	192.3 dB
Satellite		Kashima S-band earth station	
Rx antenna gain	23.8 dBi	Rx antenna gain	33.5 dBi
Feed loss	2.8 dB	Feed loss	0.8 dB
Rx power (at LNA in)	-115.5 dBm	Rx power (at LNA in)	-77.6 dBm
System noise temp.	510 K	System noise temp.	265 K
System G/T	-6.1 dBK	System G/T	8.5 dBK
Up-link C/No	56.0 dBHz	Down-link C/No	96.8 dBHz
		Return Link Total C/No	56.0 dBHz

3 Flight experiment

3.1 Experiment parameters

The C/No value on the satellite link expected in level flight is not so large: approximately 56 dBHz. Measurement time in flight is limited. Therefore, QPSK was selected as the modulation method. The Information transmission amount for collecting statistical data was secured while the packet signal transmission speed was set to 10 kbps. The non-modulation wave signal for measuring power was not transmitted simultaneously by another frequency. The receiving packet signal power modulation was measured by setting the spectrum analyzer resolution bandwidth to 30 kHz. Error correcting code was not used. The signal length of the packet signal used for transmission was 100 bytes. The satellite tracking methods used in the aeronautical earth station included the step track closed loop method, and an open loop method using information about the position and direction of the aircraft as a control. In the flight experiment, received power was measured by both methods for comparison. With regard to the evaluation of satellite link, data reception characteristics were obtained during level flight, and data reception characteristics during turning flight at an angle of tilt 20 degrees. In the image transmission experiment during the same flight, the signal transmission rate was set to 128 kbps and a turbo code with a code rate 3/4 was used as an error-correcting code. Therefore, the information rate in the image transmission experiment was 96 kbps. With regard to the image signal, an image file with a size of 654 Kbyte was transferred by File Transfer Protocol (FTP) and the transfer time was measured.

3.2 Experimental result

(1) Received signal characteristics

A signal was transmitted from the aeronautical earth station to the S-band base station at Kashima Space Technology Center via the satellite and the received power was measured in order to find the propagation condition during signal transmission. Figure 2 shows the fluctuation of received power during level flight. The antenna was controlled by an open loop control method where the satellite was tracked according to information such as its attitude. Figure 2 shows the received signal level is stable and the fluctuation width is within 1dB.

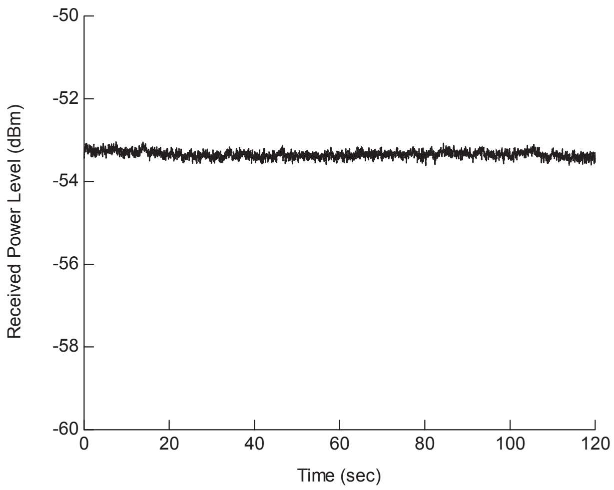

Fig. 2 Received power on level flight with open loop satellite tracking

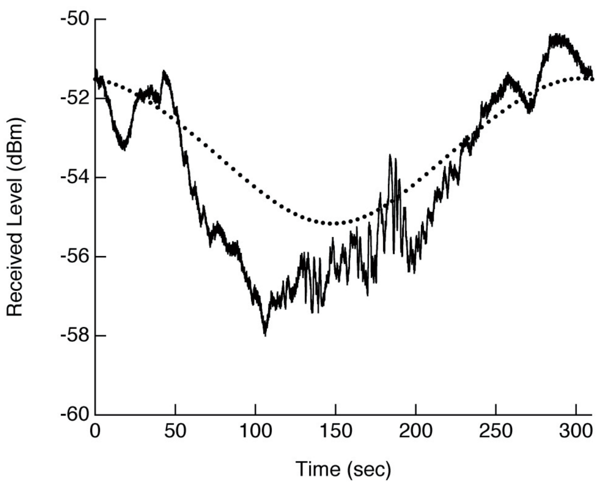

Fig. 3 Received power in turning flight with open loop satellite tracking (20 degrees bank angle)

In Figure 3, solid lines show the fluctuation of received power value measured by the aircraft during turning at a tilt angle of 20 degrees. The aircraft circled clockwise 360 degrees over Itako city, Ibaraki prefecture, starting toward the east. Dotted lines show the values of calculated received power at the S-band base station.

The value in Fig. 3 was calculated by the following procedure. The relative elevation angle of the satellite seen from the aircraft changes nearly in a sinusoidal wave against the traveling direction of the airplane (yaw axis) between approximately 30 to 70 degrees. Figure 4 shows the calculated relative elevation angle of ETS-VIII seen from the aircraft circling above Itako city. The antenna was a flat, phased array antenna. If the antenna is on a flat plane, the smaller the satellite elevation angle is, the smaller the antenna gain gets. In Figure. 5, circles show the actual measured value of antenna transmission gain against satellite elevation angle when the antenna is horizontal. The dotted line in Fig. 5 is a function curve estimated from actual measured values. Based on data in Figs. 4 and 5, it is possible to find the antenna transmission gain against

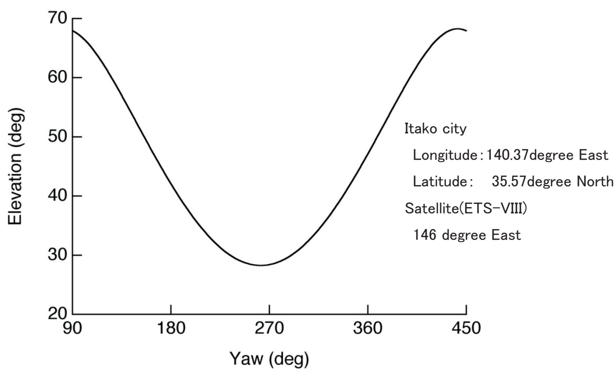

Fig. 4 Elevation angle in turning flight over Itako city (20 degrees bank angle)

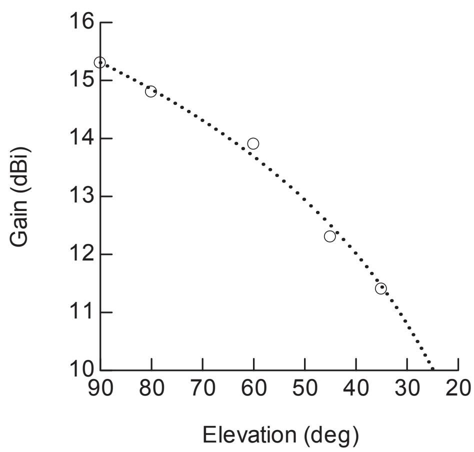

Fig. 5 Elevation angle versus transmitting antenna gain

traveling direction of a circling aircraft. By using the obtained gain, the link budget in Table 2, and the level diagram of the S-band base station, the received signal power value during flight can be calculated.

In the antenna part, 18 antenna elements are arranged in circular symmetry. If the antenna gain in the azimuth angle is stable, the power value will change in a sinusoidal wave curve like the calculated dotted line curve. As shown by the solid line in Fig. 3, the received level change is slightly different form a sinusoidal wave curve. The causes of error include gaps in flight attitude in roll and pitch axis, and variations in the receiving antenna gain in azimuth angle direction. The transmission gain of the aeronautical earth station antenna is not measured on a 3D basis. However, at an elevation angle of 45 degrees, each transmission gain at azimuth angle of 0, 90, 180, and 270 degrees was measured. The measured values were 12.3 dBi, 13.9 dBi, 13.1 dBi and 13.5 dBi. There is a difference of approximately 1.5 dB only within measured points.

The method of satellite tracking by antenna also included closed loop control by the step-track method. In this method, measurement was performed at a tilt angle of 20 degrees: Figure 6 shows the result. The fluctuation of the received level is larger than the open loop since the satellite is tracked by the step track method and the beam direction is moving continuously. However, level fluctuation shows a similar trait.

In Figure 6, receiving level data is lacking from approximately 160 to 170 seconds, it shows that trouble occurred in the data collection system at the earth station. During this period, the aircraft received signals from the satellite. In the case of closed loop control, land mobile satellite communication experiments showed that a satellite could still be tracked even if there was an angle change of approximately 30 degrees per second. In this experiment, it is estimated that the antenna did not lose the satellite, but actually tracked it since the angle of the aircraft changed 5 degrees or less per second in the closed loop method. The reception level characteristics of the open loop method and the closed loop method show almost the same results. Thus, it's considered that the satellite was also tracked by open loop method.

(2) Packet signal transmission characteristics[9]

As basic performance of data transmission, the throughput of packet signal toward the received C/No was measured during the flight by open loop control to track the satellite. Figure 7 shows the result. Circles show the data in a static condition. The measurement time of each circle is from 3 to 5 minutes. Inverted triangles show the data of level flight. The measurement time of each inverted triangle is 10 seconds. The reception level is almost stable. There is a little variation in throughput because the measured packet number is small. However, if it is averaged, the throughput value towards the C/No value in the case of level flight is almost the same as that in the case of a static condition. ×-indication is the data, shown in Fig. 7, when the aircraft is turning at a tilt of 20 degrees. The measurement time of ×-indication is also 10 seconds. There are significant variations in reception level and throughput since the aircraft changes its attitude significantly. Figure 7 shows that C/No value with degraded throughput performance is lower than that of static condition and level flight by 2 dB. We exploited the

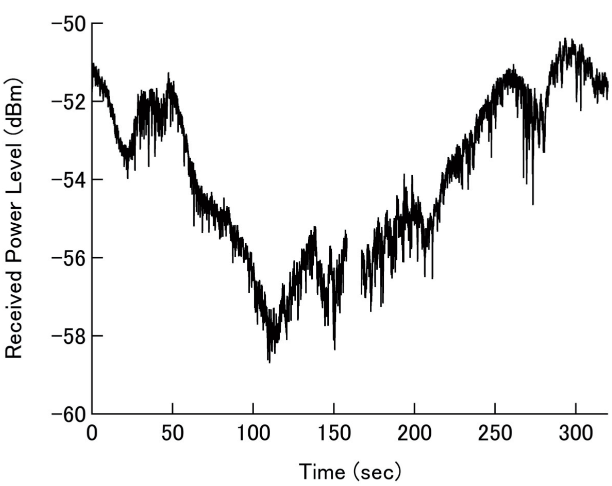

Fig. 6 Received power in turning flight with closed loop satellite tracking (20 degrees bank angle)

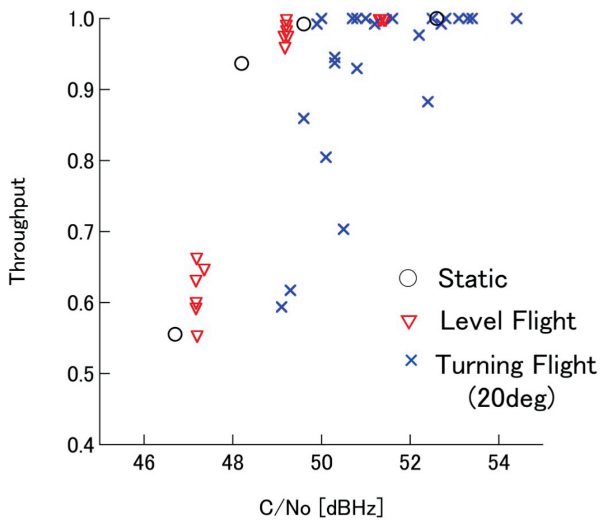

Fig. 7 Throughput performance

Table 3 Image data file transmission test

Modulation：QPSK
Transmission rate：128kbps
Error correction：Turbo code（coding rate = 3/4）
Information rate：96kbps
Image data size：654Kbyte
Protocol：File Transfer Protocol
Transmission period：62seconds
Actual information rate：86.4kbps
Efficiency：90%

possibility that the S-band frequency was usable for aeronautical satellite communication on a technical basis.

(3) Image signal transmission characteristics

The purpose of the image signal transmission experiment was to transmit image data from the synthetic aperture radar that could be useful to understand conditions in distressed areas of the world using a satellite communication system that was not affected by their disasters. Table 3 shows the experimental conditions and results. The transmission in Table 3 was performed in level flight where the attitude of the aircraft was stable. Line quality was low and the realized data transmission speed was as low as approximately 100 kbps. Until this point, an aircraft would have to land on the ground to collect data. The length of time can be significantly shortened by transmitting data from an aircraft to the ground via satellite link. Information can be collected at an early stage. When an aircraft turns, the fluctuation width of the signal level is large and file transmission is incomplete and terminated. In the future, we should make a data transmission protocol that can correspond to level fluctuation. That is a challenge for mobile satellite communications.

4 Summary

We performed an aeronautical mobile satellite communication experiment in the S-band using the Engineering Test Satellite VIII. It was confirmed that data transmission characteristics during level flight where the signal level is stable were almost the same as those of the static condition. The throughput performance in turning with a tilt angle of 20 degrees was degraded by approximately 2 dB on the basis of the C/No value compared to level flight or a static condition. This experiment showed that the S-band frequency could be used in aeronautical mobile satellite communication from a technical point of view, though transmission characteristics are slightly degraded if an aircraft significantly changes its attitude. In the image transmission experiment, the satellite link quality was low and the realized data transmission speed was as low as approximately 100 kbps. However we are planning in the future to construct a system that realizes aeronautical mobile satellite communication with a high transmission rate of over 10 Mbps using the Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) currently being operated.

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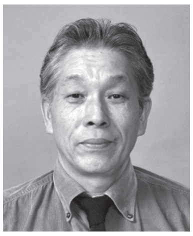

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