Evaluation Experiment of the Base Earth Station

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For the measurement of the electrical characteristics of the satellite and communication experiment using ETS-VIII satellite, was installed the Ka-band feeder link station and S-band earth station at NICT Kashima Space technology Center. Earth station has the ability to send and receive signals stably for performing various satellite communication experiments, and is constituted to can measure the power and frequency of the signal. Carried out the performance test of the earth station regularly, and understand the electrical performance of the devices constituting it, and was in response to changes in the characteristics due to aging.

1 Introduction

For the communication experiments and the measurements of the electric characteristics of the satellite using the Engineering Test Satellite VIII (ETS-VIII), the Ka-band feeder link station and the S-band earth station were installed to Kashima Space Technology Center (Kashima City, Ibaraki Prefecture).

The Ka-band feeder link station forms a feeder link between ETS-VIII and ground and plays a central role in various communication experiments. Further, the S-band earth station forms a service link between ETS-VIII and the ground which is used as the reference station of personal satellite communication experiments.

The Ka-band feeder link station is used as the base station for high-speed packet communication via the packet switch and the voice and data communications via the onboard processor, further, in the high quality multicast experiment for mobiles, it was used as the base station for transmitting a signal.

In this paper, we evaluated the electrical characteristics from results of a periodic performance test for the Ka-band feeder link station and S-band earth station. Further, the results of the evaluation of the Ka-band feeder link station automatic antenna tracking function and automatic frequency control (AFC) functions were reported.

2 Composition of earth station

Figure 1 shows the composition of Ka-band feeder link station and Fig. 2 shows the composition of S-band earth station.

The experiments in Ka-band used two frequency bands of High-Band (transmission: 30.6356 ~ 30.63801 GHz, reception: 20.8328 ~ 20.8353 GHz) and Low-Band (transmission: 30.5684 ~ 30.5709 GHz, reception: 20.7872 ~ 20.7897 GHz). In the composition diagram, High-Band is represented as (H) and Low-band as (L).

HPA : High Power Amplifier
20G LNA : 20 GHz band Low Noise amplifier
30G U/C : 30 GHz band frequency converter for transmission (Up-Converter)
20 G D/C : 20 GHz band frequency converter for reception (Down-Converter)
1G COMB : 1 GHz band signal Combiner
1G DIV : 1 GHz band signal Divider
20W SSPA : 20 W Solid State Power Amplifier
LNA : Low Noise Amplifier
U/C : Frequency converter for transmission (Up-Converter)
D/C : Frequency converter for reception (Down-Converter)

Details of particulars of primary devices constituting each earth station are shown in the references[1][2]. Then, the main specifications of the antenna unit only are shown in Tables 1 and 2.

3 Results of evaluation

3.1 Ka-band feeder link earth station

3.1.1 Transmission and reception system level diagram

Figure 3 shows the level diagram of the transmission

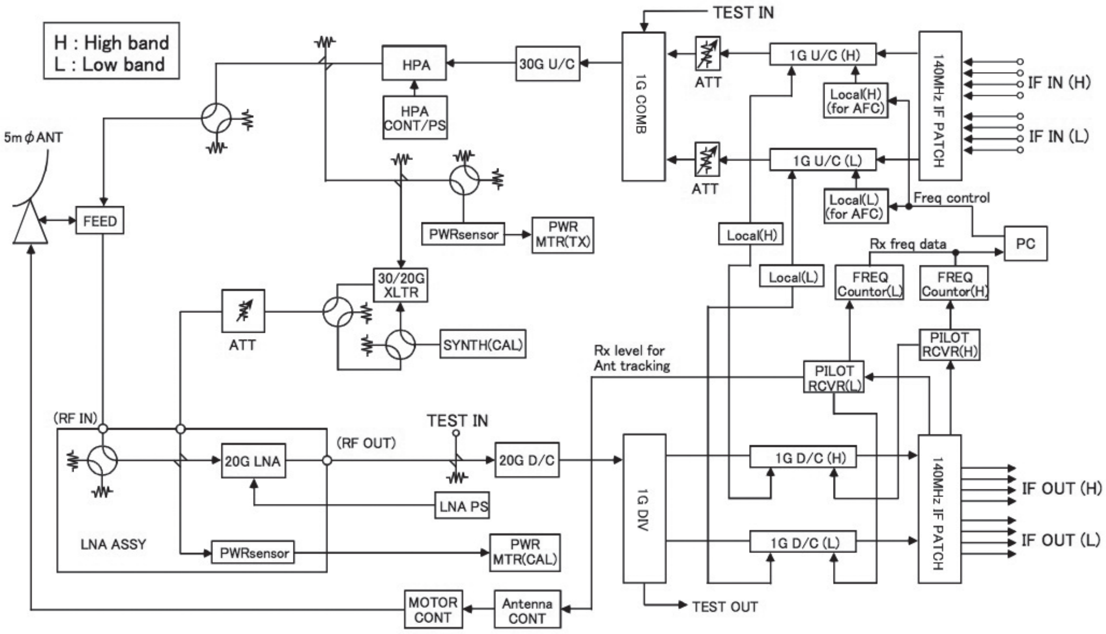


Fig. 1 Block diagram of Ka-band feeder link station

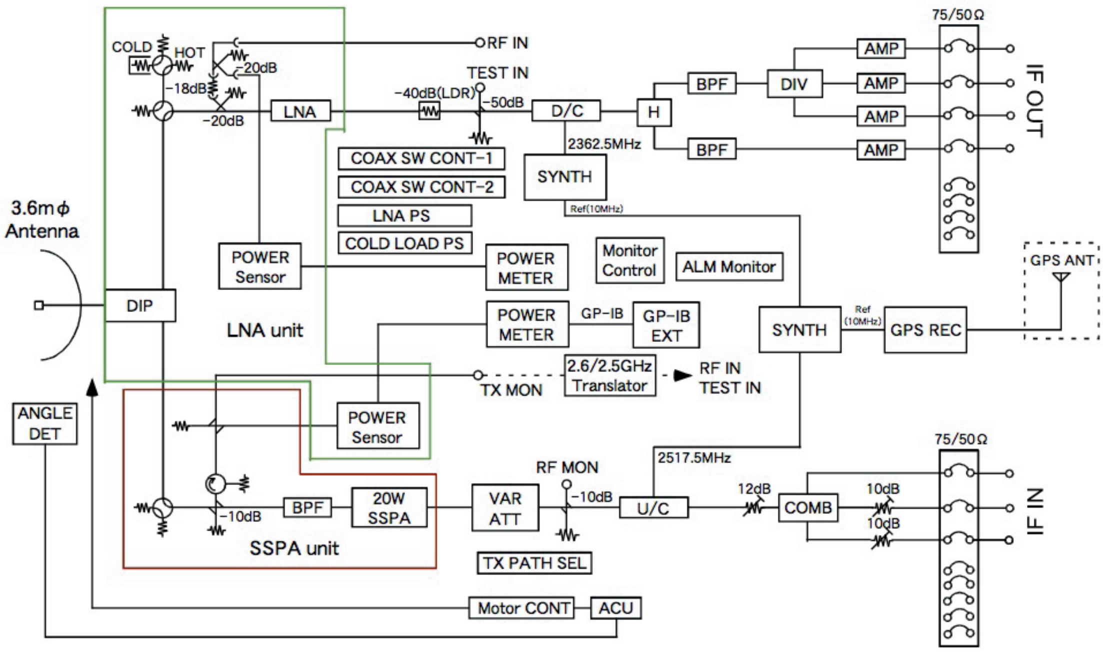


Fig. 2 Block diagram of S-band earth station

and reception system of the Ka-band feeder link station. The level diagram was acquired at the time of installation and from a performance test carried out once a year. Level diagram at installation was obtained to check if electrical characteristics of the earth station after installation works are normal. After the satellite launch, the level diagram was adjusted by actually transmitting and receiving to the satellite, and it was determined to be the same as the initial level diagram. The level diagram is used to confirm that each device constituting the earth station is functioning normally and to evaluate measurements of transmission and receiving signal level to the satellite.

Each measurement value was taken at the input/output terminals of each device constituting the earth station. However, antenna gain value is used for inspection results at manufacturing. When a variation of the level diagram was noticed at a performance test, adjustments were made to the initial level diagram. With level diagram of transmit system in 2011, output of the power amplifier was about 4 dB lower. This is due to the fact that the power amplifier failure, after the earthquake disaster occurred in March 2011, was switched to the auxiliary system. In the

Table 1 Main specifications of Antenna unit of Ka-band feeder link station

Mechanical performance

Item	Performance
Antenna aperture diameter	5.0m (Effective diameter)
Antenna type	Cassegrain
Mount type	AZ-EL
Drive range	EL: Initial set angle ±5°
	AZ : Initial set angle ±10°
Drive speed (Nominal Value)	Elevation: 0.005°/sec
	Azimuth : 0.007°/sec
Tracking accuracy (at a mean wind velocity of 20m/sec)	0.002° rms (for both AZ and EL)
Main reflector accuracy	0.25mm rms (at installation)
Operatable wind velocity	Mean 20m/sec 30m/sec (momentary maximum)
Wind velocity resistance	60m/sec (momentary maximum)

Electric performance

Item	Performance	
	Transmission	Reception
Frequency band	30.56GHz～30.68GHz	20.78MHz～20.84GHz
Polarization	RHCP	LHCP
Gain	62.1 dBi (feed unit input)	59.1 dBi (feed unit output)
Noise temperature (LNA input)	–	57.4K (feed unit output)
VSWR (feed unit)	1.07 or less	1.04 or less
Sidelobe characteristics	96.6%	99.5%
Axial ratio	2.7 dB or less	2.3 dB or less
Isolation	-100 dB or better	
G/T	–	35.8 dB/K

Table 2 Main specifications of Antenna unit of S-band earth station

Mechanical performance

Item	Performance
Antenna aperture diameter	3.6m (Nominal)
Antenna type	Parabola
	Primary radiator: cross dipole
Mount type	AZ-EL
Drive range (software limit)	Elevation : 27.32°～62.47°
	Azimuth : 155.85°～187.44°
Drive speed	Elevation : 0.24°/s
	Azimuth : 0.21°/s
Operatable wind velocity	30m/s (momentary maximum)
Nondestructive wind velocity	60m/s (momentary maximum)

Electrical performance

Item	Performance	
	Transmission	Reception
Frequency	2657.5MHz±2.5MHz	2520.0MHz±20MHz
Polarization	LHCP	
Gain	35.80 dBi (Diplexer input port)	34.54 dBi (LNA input port)
Noise temperature (LNA input)	–	113.01 K (Elevation: 45°)
VSWR	1.26 or less (Diplexer output port)	1.04 or less
Axial ratio	1.12 dB	0.82 dB
Isolation	90 dB or more	
G/T	–	9.29 dB/K

communication experiments, because the value of the transmit power of the earth station was measured by power meter, the change in the gain of the power amplifier has been confirmed that there is no hindrance in the experiments. There was no significant change in the experimental period within the reception system level diagram.

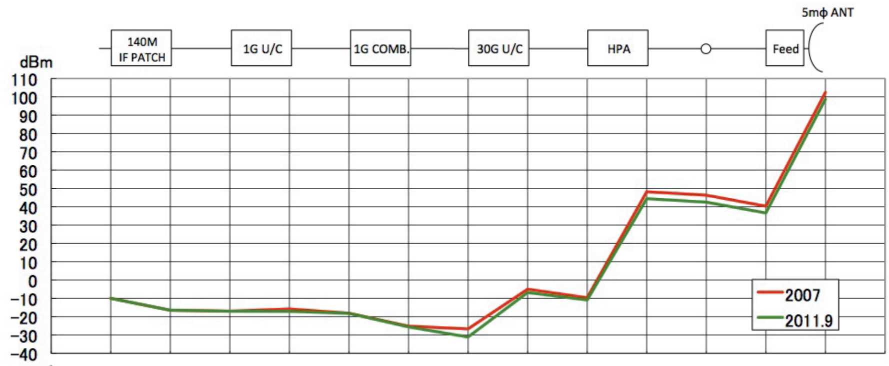
In the Ka-band feeder link station, the Equivalent Isotropic Radiated Power (EIRP) of the transmission signal and the reception antenna input power of the received signal were obtained from Fig. 4.

The transmission power was set so that the power of the signal at the interface point with the antenna system of the earth station can be read directly by the power meter, while EIRP was obtained by calculation from power meter measurement, loss from the interface point, and antenna gain.

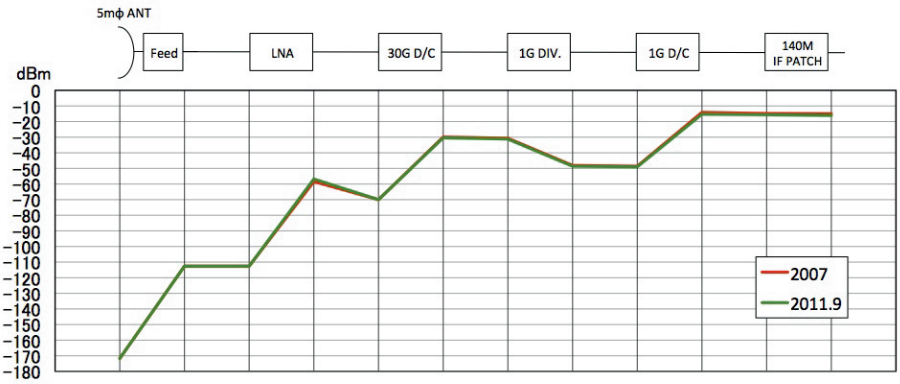
The power of the received signal from the satellite is able to determine the antenna input power, based on the receiving system level diagram which shown in Fig. 3 and the received signal level which measured at the output terminal of 140 MHz IF PATCH which shown in Fig. 1. However, for amplitude frequency characteristics of the reception system, a certain amplitude variation is allowed in the earth station specifications, and therefore, calculated value of the antenna input power may include errors depending on the frequency of the signal to be measured. When necessary to perform accurate measurement, such as electric characteristics of the transponder of the satellite in electric performance test, a signal which having equivalent strength with received signal from the satellite is input to the coupler placed front of low-noise amplifier (LNA ASSY) shown in Fig. 4 (2) from calibration signal input terminal (CAL IN) using signal generator (SG) , to obtain accurate antenna input power from the reception antenna gain and the input power (RF IN) the low noise amplifier obtained.

When a beacon signal in Ka-band being transmitted from the satellite is received, transmission EIRP of the satellite is obtained using the reception system level diagram in Fig. 3 from the received signal level measured at the output terminal of 140 MHz IF PATCH. Results obtained are shown in Table 3.

The gain of 140 MHz IF PATCH output terminal, Low-Band is 137.0 dB, High-Band is 137.4 dB, including antenna gain of the reception system, and propagation loss, Low-Band is 210.21 dB and High-Band is 210.23 dB, from calculation of free space propagation loss, and loss in the atmosphere on clear day is 0.39 dB (from approximation formula of ITU, 1994 a, ITU, 1994 b). The transmit EIRP (Kashima direction) of the satellite of each beacon signal was obtained by calculation, to be Low-Band is + 60.89 dBm and High-Band is + 60.61 dBm. From results of protoflight test of the satellite before launch[3], the transmission EIRP

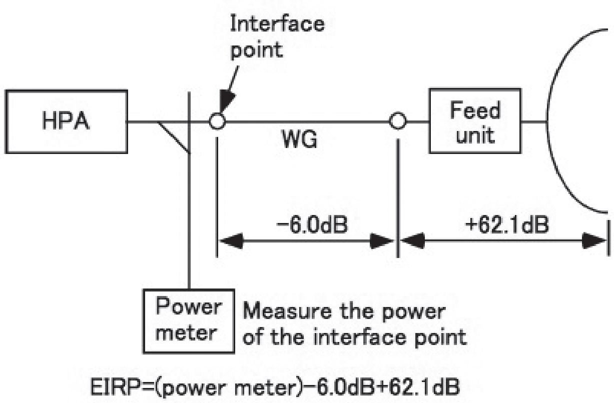


(1) Level diagram of the transmitter

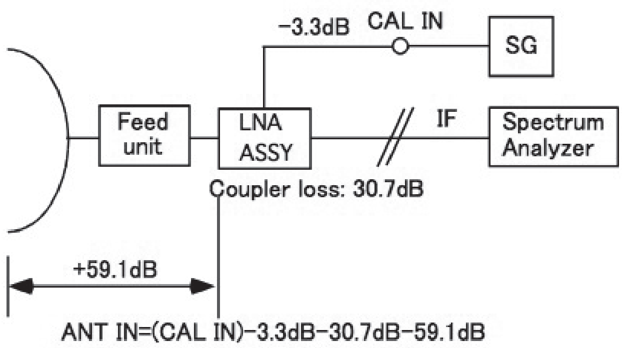


(2) Level diagram of the receiver

Fig. 3 Level diagram of Ka-band feeder link station



(1) EIRP



(2) Antenna input power

Fig. 4 Transmit and receive power measurement of Ka-band feeder link station of Ka-band beacon signal when used antenna gain of Kashima direction, is 61.8 dBm (standard value) for both Low-Band beacon and High-Band beacon. And the satellite EIRP obtained from the receiving level is about 1 dB lower than the standard value. However, if amplitude frequency characteristics of the earth station, antenna directivity error in orbit, and calculation error of propagation path are taken into considerations, results obtained well conform to each other. It shown from this that the transmission EIRP of the Ka-band of satellite could be obtained with error of about 1 dB if level diagram of the receiving system is accurately determined.

3.1.2 Antenna automatic tracking function and automatic frequency control function

The Ka-band feeder link station performs the automatic tracking of parabolic antenna (5 mϕ) and the automatic frequency control, by receiving beacon signal from the satellite.

The method of automatic antenna tracking is using the step tracking method, which actual measurement value of one step is 0.0140 deg. in azimuth direction and 0.0110 deg. in elevation direction.

Table 4 shows the antenna tracking accuracy measured at performance test. As for tracking accuracy, the trajectory of the step track was recorded for about 30 minutes after directing the beam towards the center of the satellite, and calculated by the angle of the antenna which was moved by step tracking, meanwhile and the frequency of each step. Overall tracking accuracy is calculated by tracking accuracy of the azimuth and elevation direction.

According to the performance test carried out in September 2011, tracking accuracy deteriorated from the previous measurement. This is considered to be attributable to the damage caused by the Great Eastern Japan Earthquake occurred in March 2011. Results of the damage survey conducted after the earthquake, of the azimuth rails are subsidence a few mm from the horizontal to the east has been confirmed. Further, although it was confirmed that the antenna rotated normally by the electric motor in the range of the antenna driving during ordinary experimentation, the friction torque was non-standard depending on the angle, and has given an obstacle to the movement of the antenna. In addition, there was no significant difference in the measurement result in the regular performance test before the earthquake.

Power half-width value of the 5 mϕ parabolic antenna is about 0.15 deg., overall tracking accuracy after the earthquake has become about 1/3, but there was no major obstacle to the experiment.

Figure 5 shows the plot for one hour of the level of Ka-band beacon signal which measured at IF while performed the antenna automatic tracking. The antenna automatic tracking performed intermittently, and can set the time interval for the next operation, from the end of operation of the automatic tracking. Figure 5 shows a case where this time interval is set to 20 min. Magnitude of level fluctuation with this setting is about 0.5 dB by only

Table 3 The Satellite EIRP of Ka-band beacon signal

	level of IF output signal (dBm)	antenna input power (dBm)	atmospheric loss (dB)	propagation loss (dB)	satellite EIRP (dBm)
Low-Band	-12.9	-149.9	0.39	210.21	60.70
High-Band	-12.8	-150.2	0.39	210.23	60.42

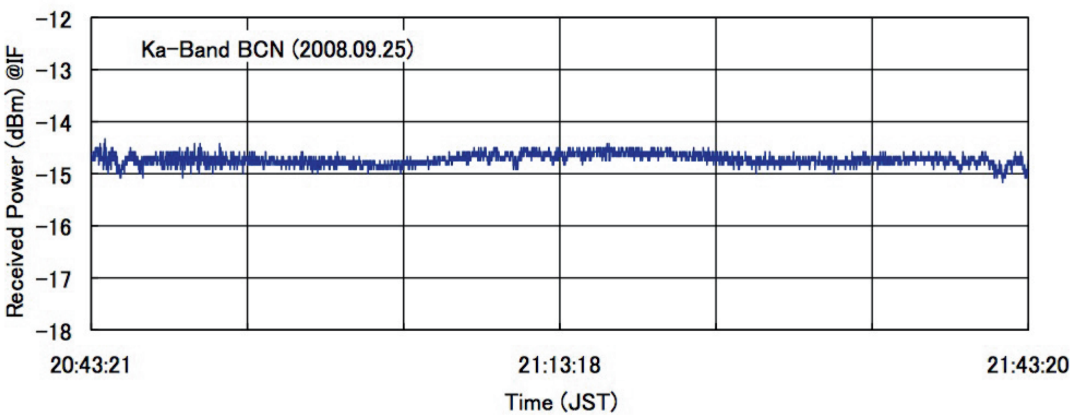


Fig. 5 Level fluctuations of Ka-band beacon signal of the automatic tracking operation

downlink of the beacon signal. When Ka-band uplink signal sent from the parabolic antenna (5mϕ), the level fluctuation combining uplink and downlink occurs at Ka-band downlink signal from the satellite because similar fluctuation is generated also in the uplink.

Time interval to actuate automatic tracking could be set to arbitrary time and in the experiment, it was set so that fluctuation of transmission and reception level might not be hindered by contents of the experiment.

AFC function of the receiving unit is to compensate automatically for the variation of transmission frequency of the satellite and the frequency variation by Doppler shift by movement of the satellite.

This is an important function since in Ka-band, the frequency variation of the local signal used for frequency conversion of the transponder and the frequency variation by Doppler shift by movements of the satellite become excessive. Fig. 6 shows the composition of reception AFC of Ka-band feeder link station.

The IF output of Ka-band beacon signal received is input to the pilot receiver, compared with the receiving frequency of beacon signal (nominal value) in IF (140 MHz band), and the error information is superimposed on the reference signal (10 MHz) of the local signal generator (PLO) of 1 GHz band frequency converter, then control the receiving frequency by this composition,.

The beacon signal are in High-Band (H) and Low-Band (L), the pilot signal receiving equipment is also equipped one for each.

AFC detects a difference between the frequency of beacon signal input to the pilot signal receiver and the frequency of beacon signal (nominal value), and controls frequency of the oscillator which in 1 GHz frequency converter so as to compensate for frequency deviation. Actual measurement of control one step width is 117.64 Hz.

Figure 7 shown the results of beacon signal receiving; (1) is a case where AFC was not used, (2) is a case where control by AFC was performed. In (1), the frequency of the received beacon signal have observed changes in the frequency of about - 500 Hz to - 900 Hz, to the nominal frequency, and in (2) that frequency variation could be controlled within the range of control step width. The measurement frequency includes a measurement error by frequency resolution which was set to the spectrum analyzer.

Table 4 Measurement results of automatic tracking accuracy

Measurement ate	Azimuth (deg rms)	Elevation (deg rms)	Overall (deg rms)
2009.3	0.01484	0.01166	0.01887
2010.3	0.01345	0.00993	0.01671
2011.9	0.0352	0.0269	0.0443

3.2 S-band earth station

Figure 8 shows the level diagram of the transmission and reception system of S-band earth station. The level diagram was acquired at installation and a periodical performance test was carried out annually in a similar as the Ka-band feeder link station. The level diagram is used to confirm that each device constituting the earth station is

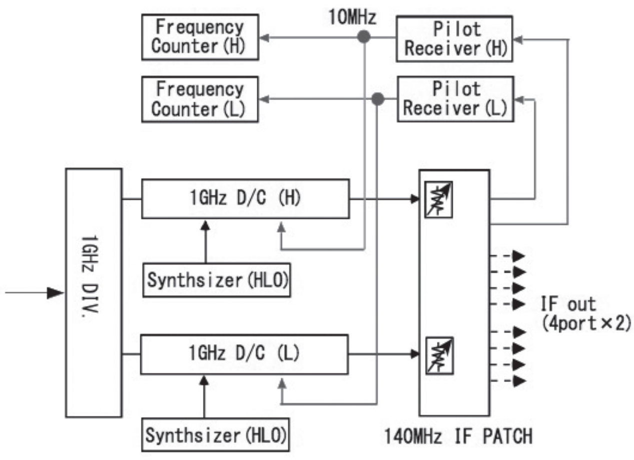
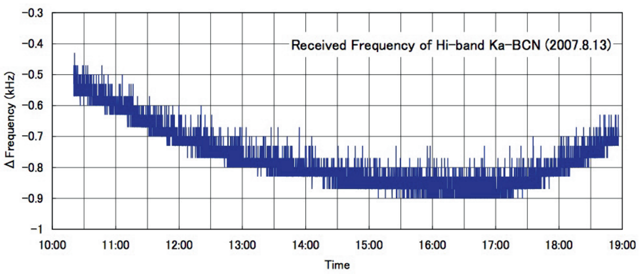
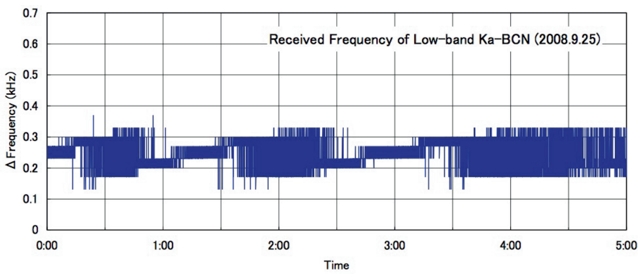


Fig. 6 Block diagram of automatic receive frequency control



(1) Frequency fluctuation (when there is no AFC)

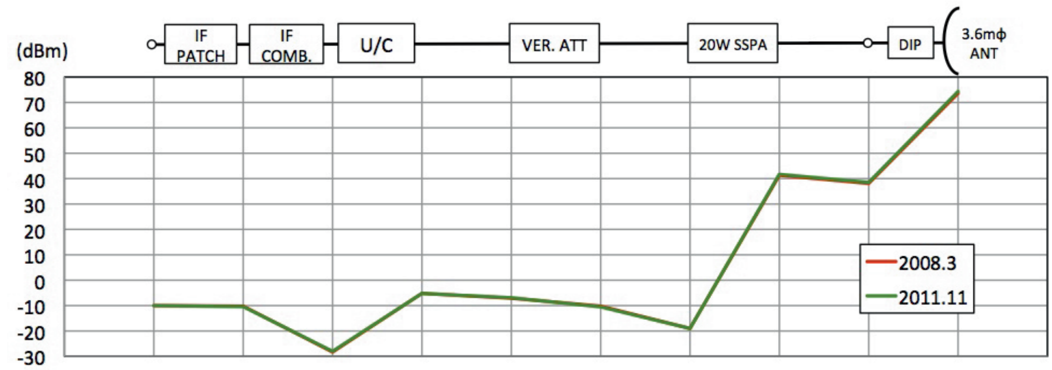


(2) Frequency fluctuation (when there is AFC)

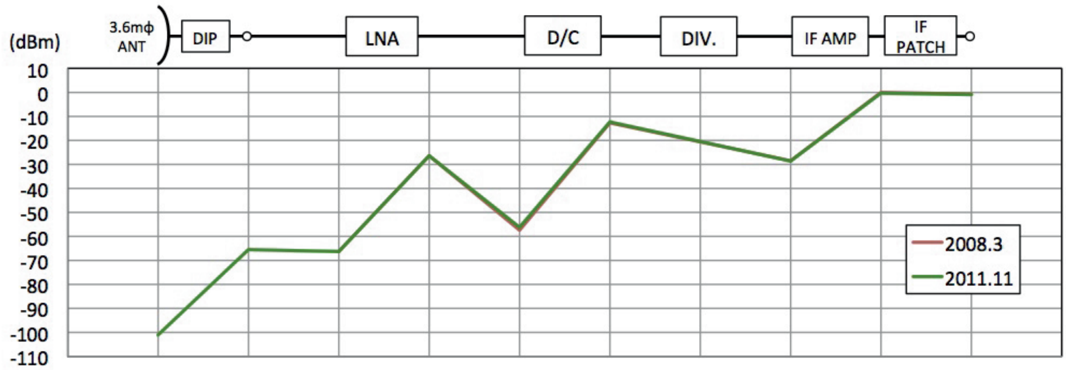
Fig. 7 Frequency fluctuation of the received beacon signal operating properly, and used to evaluate measurements of transmission and reception signal level with regard to the satellite.

After the launch of the satellite, the level diagram was adjusted by transmitting and receiving signals to the satellite practically, and was determined to be that of as the initial level diagram. S-band earth station is designed supposing that the large deployable antenna of the satellite may become unavailable. In fact, the large deployable antenna for reception became unavailable after the launch and the level diagram was then adjusted to cope with this trouble.

Each measurement value was measured at input/output terminal of each device constituting the earth station. However, the antenna gain used inspection results of manufacturing. When there is a change in the level diagram in periodic performance test, it was adjusted to the initial level diagram. During the period of experiments, there was no significant change in the level diagram in the transmission system and reception system.

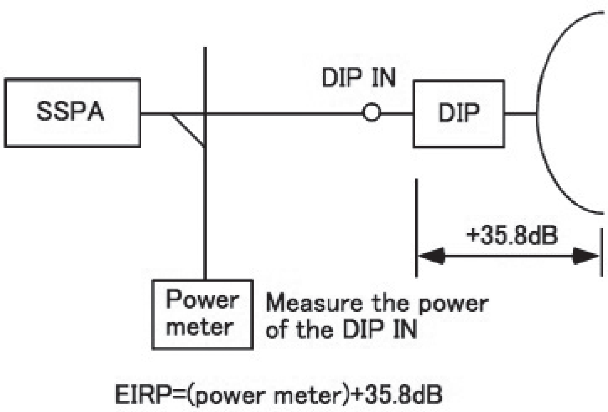


(1) Level diagram of the transmitter

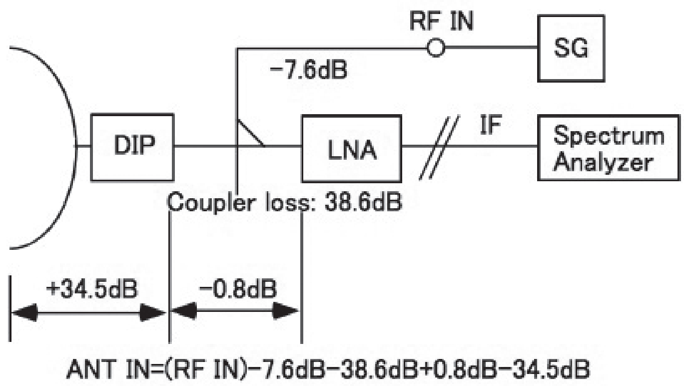


(2) Level diagram of the receiver

Fig. 8 Level diagram of S-band reference station



(1) EIRP



(2) Antenna input power

Fig. 9 Transmit and receive power measurement of S-band earth station

The Equivalent Isotropically Radiated Power (EIRP) of the transmitted signal and the antenna input power of the received signal of S-band earth station were obtained from Fig. 9.

The transmission power in the DIP IN which is an interface point of the earth station with antenna system was set to be able to read directly by the power meter shown in Fig. 9 (1). EIRP was obtained by calculation of the antenna gain and loss from the interface point, using values measured by a power meter.

For the received power of the signal from the satellite, an antenna input power can be determined using the reception system level diagram shown in Fig. 8 and the received signal level which measured in IF output terminal (IF OUT) of the block diagram of the earth station shown in Fig. 2. However, since the variation of the constant amplitude is allowed in the specification of the earth station, from the amplitude frequency characteristics of the reception system, as in the Ka-band feeder link station, error is included in the calculated value of the antenna input power by the measured frequency of the signal. When electric characteristics of the transponder of the satellite are measured in the performance test of the satellite, and an accurate measurement is required, a signal having strength equivalent to the receiving signal from the satellite is input to the coupler provided before low-noise amplifier (LNA) shown in Fig. 9 (2) from signal input terminal (RF IN) for calibration using a signal generator (SG) and the like, and antenna input power is calculated from its electric power.

Half-power beamwidth of the antenna of S-band earth station is wide as few degrees, and frequency is low. Therefore, the frequency variation of the received signal due to the Doppler shift and the like is small. Since this, antenna automatic tracking function and AFC function are not provided.

4 Conclusions

ETS-VIII was launched in December 2006, then until the end of the experiments in December 2012. The Ka-band feeder link station and S-band earth station reported in this paper always played central roles in the experiments.

The operating state of devices constituting the earth station was determined by the performance tests carried out periodically during the experimental period and communication experiments could be accomplished. Further, by determining the level diagram, it can be found at the early stage of malfunction etc. of the device from the signal level during the experiment, there was no major obstacle to the experiment. In addition, we observed a large sway in Kashima City, Ibaraki Prefecture in the Great East Japan Earthquake of March 2011, but the damage of the 5mϕ parabolic antenna which is the largest structure of the earth station was small, and there is no major damage being an obstacle to the experiments of the earth station. Fortunately the experiments could be continued.

Acknowledgments

The authors wish to express their thanks to those who cooperated with operation of the earth station.

Refernces

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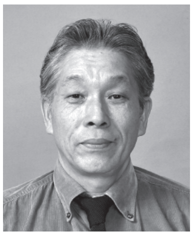
3 H. Kohata and S. Hama, "Onboard Ka-band Feeder Link Communications Equipment," Vol. 49, No. 3/4, pp. 33–41, Sept./Dec. 2003.



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