Performance Evaluation Experiments of an Onboard Packet Switch

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An onboard switch enables satellite communications systems with a multi-beam structure to operate more efficiently. The Engineering Test Satellite VIII with the onboard packet switch has been launched in December 2006. The adoption of the function as bridges for this onboard switch make it possible that the highly flexible network is constructed. The initial performance test results in the satellite orbit show that the onboard packet switch is sufficient to meet the requirements for the mobile satellite communications system. The periodic performance tests were also conducted in several times for four years. These test results show the onboard packet switch keeps the same performance for four years.

1 Introduction

Two types of switch are provided onboard the Engineering Test Satellite VIII (ETS-VIII). One is a circuit switch for voice communication and the other is a packet switch for high-speed data communication[1][2]. If the satellite has a switching function, it is possible to construct a flexible network and improved link usage efficiency can be expected. From the initial stage of ETS-VIII development, the National Institute of Information and Communications Technology has been involved in the research and development of a packet switch to be mounted on board the satellite. A mobile satellite communication system using this packet switch can achieve a 1 Mbps of data transmission rate targeting a vehicle-mounted mobile earth station and a portable type small-sized earth station[3][5]. The satellite was launched in December 2006 and placed in a geostationary orbit at 146 degrees east longitude, and then performance confirmation tests of the equipment mounted were performed. This paper deals with the results of basic performance experiments on the packet switch such matters as bit error rate and switching processing time characteristics performed after launching. As for basic characteristics, periodical performance confirmation tests, “Periodical checking” were carried out three times till completion of the experiments in December 2012, and data were obtained regarding long-term deterioration of onboard equipment which are also introduced in this paper.

2 Outline of packet switch

The packet switch (PKT) mounted on the ETS-VIII has a switching function corresponding to an Ethernet bridge. With switching control, switching operations are executed based on the information about the MAC address that is the address in the data link layer included in the frame of the packet signal received. Therefore, a regenerative repeating method, in which transmission signal is once demodulated on the satellite and modulation is performed after switching of the signal, is employed. The packet switch is composed of a modulation/demodulation unit (PKT-MODEM) and a switching control unit (PKT-CONT), and equipped with 2 ports for feeder links and 2 ports for mobile links, while switching control of the packet signal between ports is performed on the satellite. To improve reliability, the switching control unit is of a fully redundant system and in the modulation/demodulation unit, the internal oscillator and command processing system are also configured to be redundant. Since control information for the execution of switching is included in the packet, all packet signals to be transmitted are subject to regenerative repeating, and switching control is performed based on the control information obtained. Table 1 shows the principal particulars of the packet switch. Figure 1 shows a block diagram of the packet switch, and Fig. 2 shows a photograph of the onboard packet switch. The article on the left of photograph is a modulation/demodulation unit, and the two articles on the right are switching control units of the fully redundant type.

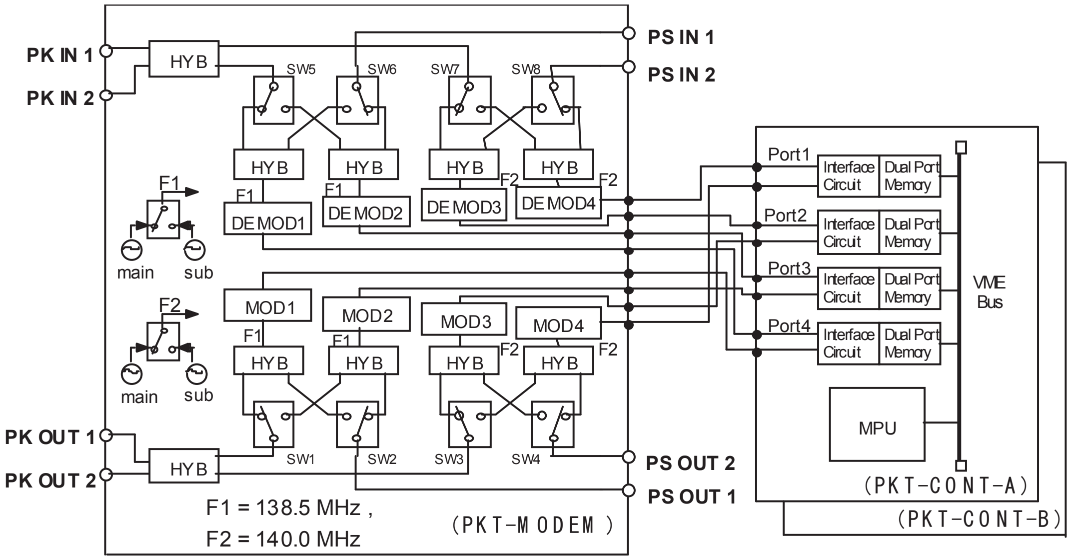

Fig. 1 Block diagram of onboard packet switch

Table 1 Major specification of onboard packet switch

Modulation:	PI/4 shift QPSK
Demodulation:	Coherent detection
Transmission rate:	1024 kbps
Error correction:	FEC, ARQ
Packet length:	8msec (normal) [32msec at maximum]
Access scheme:	Slotted ALOHA, Reserved packet
Switching function:	Bridges
Size:	MODEM part: 440×285×278 mm, Baseband switch part: 280×285×278 mm
Weight:	MODEM part: 21 kg,
Baseband switch part:	11 kg
Power consumption:	MODEM part: 86 watts, Baseband switch part: 34 watts

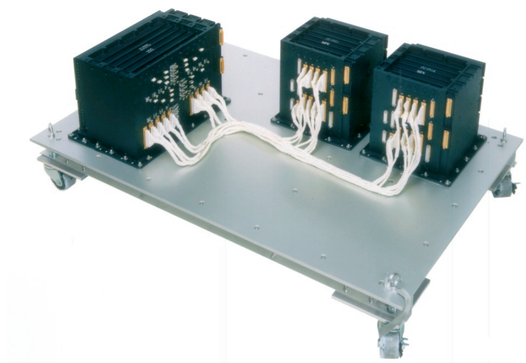

Fig. 2 Photo of onboard packet switch

Table 2 Example of link budget

Up-link (2.6 GHz)	
Mobile station	
HPA output power	43.0 dBm
Feed loss	1.0 dB
Antenna gain	6.0 dBi
Mobile station EIRP	48.0 dBm
Propagation loss	192.6 dB
Satellite	
Rx antenna gain	42.7 dBi
Feed loss	1.1 dB
Rx power (at LNA in)	-103.0 dBm
System noise temp.	520 K
System G/T	14.6 dBK
Up-link C/No	68.5 dBHz
Required C/No	64.7 dBHz
Link margin	3.8 dB

Down-link (2.5 GHz)	
Satellite	
HPA output power	47.3 dBm
Feed loss	1.5 dB
Antenna gain	40.1 dBi
Satellite EIRP	85.9 dBm
Propagation loss	192.1 dB
Mobile station	
Rx antenna gain	6.0 dBi
Feed loss	1.0 dB
Rx power (at LNA in)	-101.4 dBm
System noise temp.	450 K
System G/T	-21.5 dBK
Down-link C/No	70.7 dBHz
Required C/No	64.7 dBHz
Link margin	6.0 dB

The earth station used for high-speed data communication via the packet switch targets a vehicle-mounted mobile earth station and a portable small-size earth station. Its transmission EIRP (Equivalent Isotropically Radiated Power) is around 18 dBW, and receiving G/T is around - 22 dBK. Transmission speed on the link is 1024 kbps and as for error correction, in addition to FEC (Forward Error Correction) using convolution coding (constraint length 7, coding ratio 1/2)/Viterbi decoding (3 bit soft decision), automatic resend processing by ARQ (Auto Repeat reQuest) is performed for packet signal containing error bits. Table 2 shows an example of the link budget of the mobile link using S-band frequency.

The packet length of packet signals to be transmitted is 8 msec (normal), while expansion to a maximum of 32 msec is possible. As for the access method, to improve link efficiency and to enable continuous data transmission, random access by Slotted ALOHA and packet reservation methods are combined. For slot reservation in the packet reservation method, a burst signal by the Slotted ALOHA method is transmitted. As for the switching control, a function for reservation control is added to the switching function corresponding to an Ethernet bridge.

Figure 3 shows a concept diagram of the satellite communication system using the packet switch. In the mobile link, the 1-beam in the multibeam corresponds to the 1-segment in the network. In the packet switch, the address table of the MAC address that is an address in the data link layer is maintained and controlled. In an Ethernet, a signal input to the bridge is disposed at signal transmission in the same segment. With this system, however, when the destination earth station of the packet signal to be input to the packet switch is within the same beam, the packet signal received is not disposed, but processed by the switch and is output to the same beam. The earth station located in each beam is known by the satellite. This function is identical with the position registration function in the radio communications system having a multibeam. Further, the software for switching control employs uploading from the earth station to facilitate experiments by various protocols. In addition, the ON/OFF change-over function of FEC for experiments, functions to continuously transmit burst packet signals composed of pseudo-noise (PN) data. A non-modulated continuous wave (CW) signal sending function, a modulator output signal ON/OFF change-over function and the like are provided.

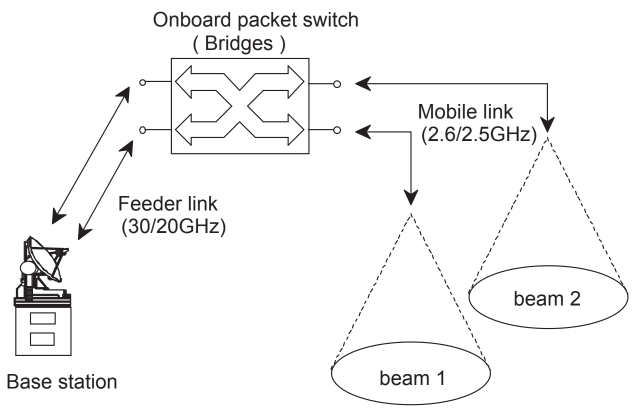

Fig. 3 Configuration of onboard packet switch network

3 Evaluation of in-orbit performance

3.1 Bit error rate characteristics

In the in-orbit performance confirmation test, first, a bit error rate (BER) that is one of basic performances of the digital modulator/demodulator was obtained. Figure 4 shows the BER characteristics with regard to Eb/No (ratio of received signal power per bit vs noise power density). During measurement, to simulate actual state under mobile environments, the repeater gain of the satellite is set so that the noise level may be held constant, and the Eb/No value was changed by changing the signal level. In Figure 4, mark ○ and mark + show the results of the ground test before satellite launching, and mark # and mark × show test results in-orbit, where performance deterioration from the theoretical value for BER of 1×10^{-5} is kept within 3 dB. Further, the dynamic range of the input signal to the demodulator is in a range of 8 to 9 dB and BER characteristics deteriorate suddenly if it exceeds the upper limit of this range. Therefore, when operated under mobile environments, the level setting of the satellite communication system should be made taking account of the dynamic range of input signal.

3.2 Frequency acquisition characteristics

Figure 5 shows bit error rate characteristics with regard to the frequency offset of the packet signal received. The frequency stability of the local oscillator in the frequency converter to be mounted on the satellite is 1×10^{-6}, and the same in the mobile station on the ground is 5×10^{-6}. If the maximum mobile speed of the mobile earth station is assumed to be 1000 km/hr, the maximum frequency offset in the mobile link using S-band (2.6/2.5 GHz) is approximately ± 20 kHz. With a feeder link using Ka-band

(30/20 GHz), the frequency is higher and change becomes greater accordingly. However, on the feeder link side, a frequency control circuit is provided to the base earth station on the ground and therefore, for the demodulator on the packet switch side, there is no problem if demodulation can be performed without deterioration of the performances in the frequency offset of ± 20 kHz. As shown in Fig. 5, there is no significant difference in the bit error rate as long as the frequency deviation is within ± 30 kHz, and it was thus confirmed that required performances are met.

3.3 Control program loading characteristics

For the software designed for the switching control, loading from the ground is made possible to enable experiments by various protocols. For uploading the control program, a Selective ARQ method is used to eliminate errors in the transmission data, and to perform uploading in a shorter time. With the ARQ method, if the quality of the link is not good and the error rate of the signal data is high, the time needed for uploading becomes longer accordingly. In the test, the time needed for uploading was measured while the quality of the link changed. The results obtained are shown in Fig. 6. The time needed for loading is shown in the figure in the form of a rate where a case packet signal free from any error is considered to be 1. Those marked by ○ and × are actual measurements, while calculated values by the computer are shown by solid lines. Calculation results in Fig. 6 show that for BER is 1×10^{-4}, the probability for that ratio of time required for loading within 1.8 is 10% and the same within 2.6 is 90%. The data length of one packet signal being transmitted is 960 bytes, and the packet error rate for BER is 1×10^{-4} is 0.53. It is known that if BER becomes greater than 1×10^{-5}, the time required for loading increases suddenly.

3.4 Characteristics of the switching processing time

In the switch, the time needed for switching processing is important. In particular, with a communication system using a geostationary satellite, since the radio wave propagation time delay between earth stations via satellite is as long as about 0.25 sec, it is desired that the signal

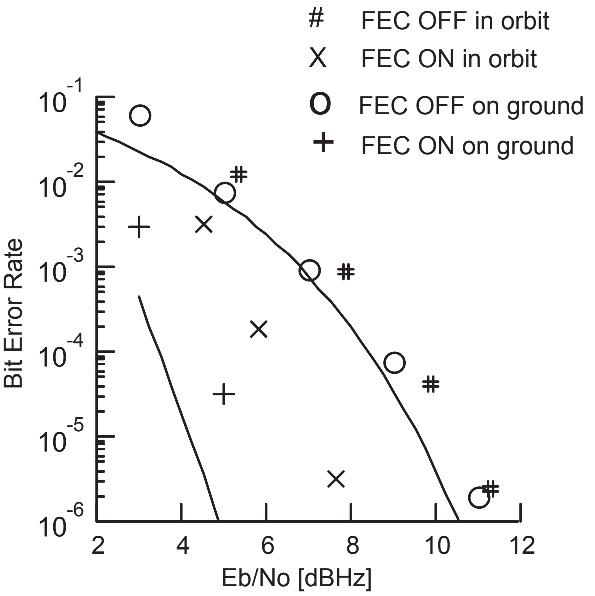

Fig. 4 BER performance

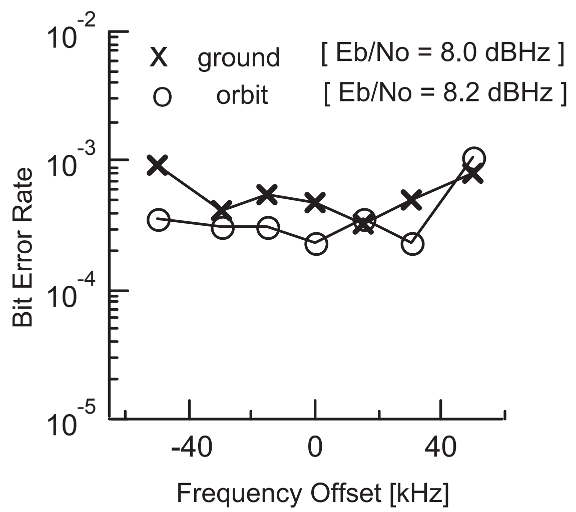

Fig. 5 BER performance against frequency offset

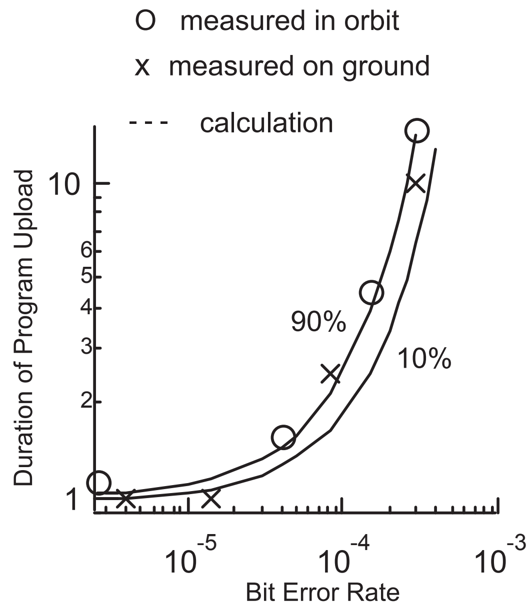

Fig. 6 Duration for program upload

processing time of the onboard equipment and earth stations should be shortened. The processing time of the onboard packet switch was obtained by measuring the time difference between packet signals transmitted via the switch and packet signals transmitted in bent-pipe mode, not via the switch. ETS-VIII has such a circuit composition that an RF signal of 2.6 GHz band received by the satellite is converted into an IF signal of 140 MHz band by the down-converter, and signal regeneration repeated via the packet switch and IF signal of 140 MHz band being repeated in bent-pipe mode can be input to the same up-converter. If these signals are sent to the ground to find the time difference between the two signals, the signal processing time delay in the packet switch could be ascertained. An example of measurements is shown in Fig. 7. A spectrum analyzer was used for the measurements and Fig. 7 shows an example screen.

In Figure 7, the leftmost signal and the signal second from the right are annunciation signals to notify the switching state of the packet switch to the ground and are output from the packet switch every about 130 msec. The signal second from the left is a signal passed through the bent-pipe mode path, and the rightmost signal is a signal being regeneratively repeated by PKT. It is noticed from Fig. 7 that the time difference between the signal second from the left and the rightmost signal, i.e. the processing time delay in the packet switch, is 88.4 msec. In the measurements, 50 separate packets were sent and the results obtained are: the minimum value of the processing time delay is about 70 msec, the maximum value about 105 msec, and the average processing time delay is 83.4 msec. With this packet switch, to improve the reliability of signal transmission, a bridge using the Stored and Forward method is used. Further, to simplify circuit composition to be used with the satellite mounted equipment, a certain amount of the signal received is accumulated in the memory and processed. Therefore, signal processing time is not sufficiently shorter as compared with radio wave propagation time delay. It is considered that with the Time Division Multiple Access (TDMA) system, or the switch in a system where signals are transmitted in the form of time-sharing as used in packet communication, some means to shorten the signal processing time delay is required, and this should be provided in the future.

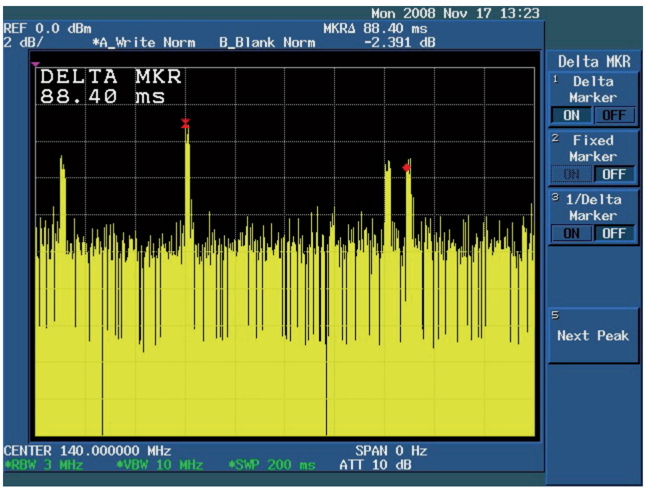

Fig. 7 An example of processing time delay measurement

In addition, since this packet switch has a bridge function, tests were carried out to confirm unicast and broadcast functions, registration of the MAC address table, alteration and aging of the timer function, flooding function and the like, to check the basic switching processing function, and to check that bridge functions are working normally even in orbit.

4 Characteristics of secular changes of basic performances

Initial performance tests of the packet switch were started in April 2007 beginning with a function confirmation test of the telemetry command signal and the like. Basic electrical performance test data were finally obtained in July to October of the same year due to schedule coordination with other experimental items. After that, the first periodical performance test was conducted in September 2008, the second test in January 2010, the third test in November 2011, while system evaluation tests and mobile satellite communication experiments of the packet switch were being conducted, and data for evaluation of long-term deterioration of the satellite mounted equipment were acquired.

This packet switch performs regenerative repeating. Therefore, for BER, that is basic performance of the digital modulator/demodulator, its characteristics were obtained at every periodical checking. Figure 8 shows Eb/No vs BER characteristics. Those marked by ○ show the results of the initial performance test, those marked by △, # and × show the results of the first, second and third periodical performance tests, respectively. For both cases, without correction and with correction by FEC, performance deterioration from the theoretical value (when BER is 1×10^{-5}) is maintained within 3 dB. No performance deterioration was seen during a lapse of time of about

4 years.

Figure 9 shows bit error rate characteristics with regard to the frequency offset of the packet signal received. In Figure 9, characteristics are shown for a case where there is no error correction by FEC and the Eb/No value is 8.0 dB, and for another case where there is error correction and Eb/No value is 6.5 dB Hz. Regarding the results of the case where there is no error correction and the Eb/No value is 8.0 dBHz, there is no significant difference in the bit error rate with regard to frequency if the frequency deviation is within ± 40 kHz, required performances are met, and no secular changes are noticed. In the case where there is error correction and the Eb/No value is 6.5 dB, one point shows several tens of error bit due to limitation of the measurement time and therefore, there are considerable scatterings in the BER value, although any event that suggests long-term deterioration is not recognized.

Figure 10 shows the results of the time needed for loading the switch control program. The time required for loading is shown as a ratio while the packet signal containing no error is considered to be 1, likewise in Fig. 6. The time required for loading increases suddenly as the BER becomes greater than 1×10^{-5} and this characteristic also shows a similar tendency suggesting that performances are well maintained.

Figure 11 shows processing time delay characteristics in periodical checking. At the time of measurement, each of 50 packet signals was output the results obtained are a minimum of about 70 msec for processing time delay, a maximum of about 105 msec, and an average of about 85 msec. The random access method is of Slotted ALOHA in which 32 msec for 4 slots are processed together (8 msec/slot). In terms of the time delay, packet signals of about 72 msec, 80 msec, 88 msec, and 96 msec will emerge at random. Of those, a part of the 96 msec signal transmits a control signal from the packet switch every about

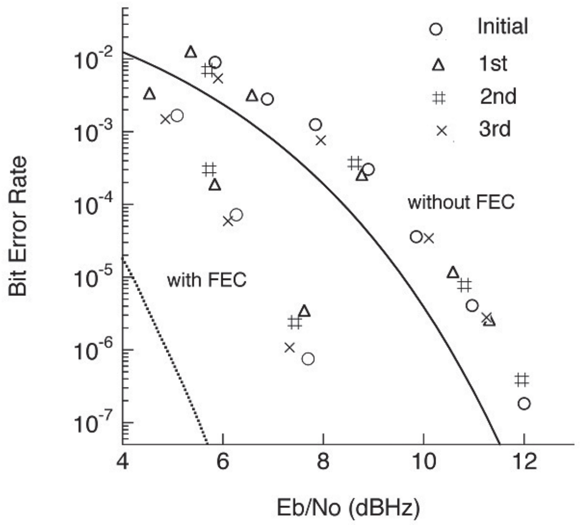

Fig. 8 BER performance in periodic tests

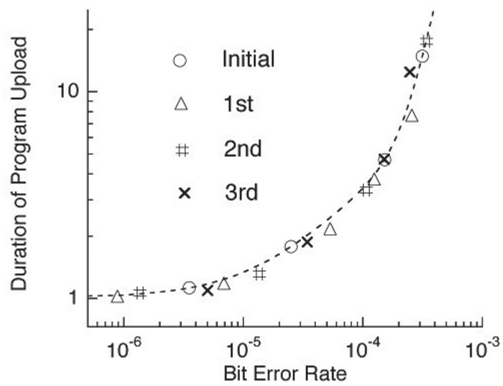

Fig. 10 Duration for program upload in periodic tests

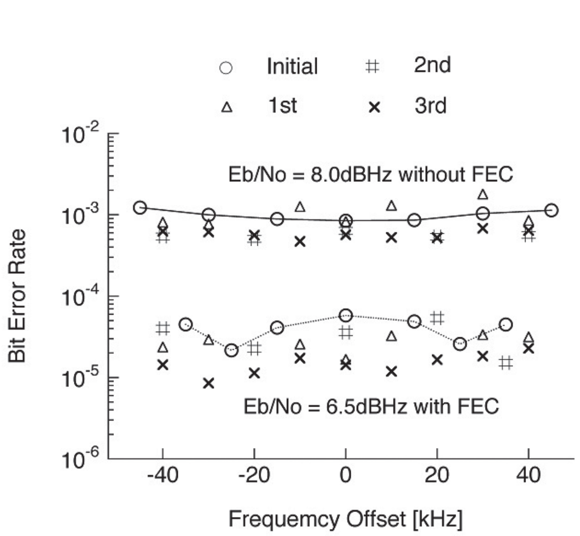

Fig. 9 BER performance against frequency offset in periodic tests

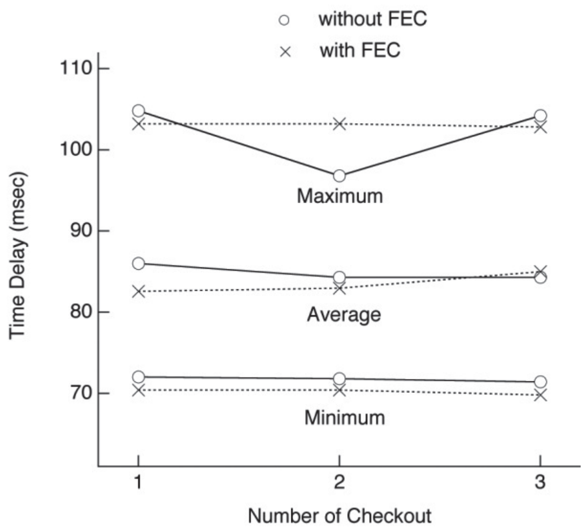

Fig. 11 Processing time delay performance in periodic tests

130 msec, and therefore a further delay of about 8 msec is caused. A packet signal that causes a delay of about 104 msec is found every 16 pieces from a probability viewpoint, while for the data free from error correction in the second periodical checking, such a signal was not found among the 50 pieces being measured, and the maximum value is smaller as compared with the results of other double measurements.

In the mobile satellite communication, the communication signal level changes due to the influences of fading in the mobile environments and therefore, the dynamic range of the input signal in the demodulator is important. In the measurements, the Eb/No value was set to a constant level, the input signal level to the packet switch was changed, while the gain of the S-RX2 that is one of the S-band down converters of the satellite was changed to obtain the BER. The gain of the S-band down-converter could be changed in 32 steps from 0 to 31, while the gain changed by about 1 dB in one step. The X-axis of Fig. 12 shows the step value of the gain.

Measurements of dynamic range was performed at the first, second and third periodical performance tests. In the first measurement, the demodulator failed to capture a signal with a step value less than 13 or more than 24. Similarly, signal capture was not possible in the second measurement with a step value less than 14 or more than 24; in the third measurement with a step value less than 14 or more than 25. Since the measured Eb/No value in each periodical performance test is slightly different, the bit error rate is also different accordingly. However, if the results are viewed from dynamic range viewpoints, the gain step value of the S-band down-converter which is capable

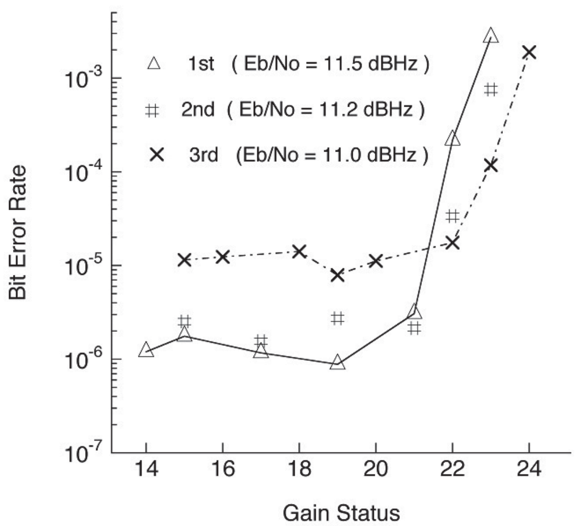

Fig. 12 Dynamic range in periodic tests

of capturing a signal increases over time, and a difference as much as about 1 dB appeared in little less than about 3 years. In terms of the dynamic range of the input signal that does not cause significant change in BER characteristics, it is about 8 dB which is considered to be changeless. The primary reasons for this are attributable to the input level to the packet switch becoming lower over time, i.e. the gain of S-band down converter was reduced. When it exceeds the upper limit or lower limit of dynamic range, a sudden deterioration of BER characteristics and failure of signal capture occur and therefore, when operated in mobile environments, the level setting of the satellite communication system should be made taking account of the dynamic range of this input signal.

5 Conclusions

Performance confirmation tests in orbit were performed for the packet switch mounted onboard the Engineering Test Satellite VIII after launching to obtain basic information such as BER characteristics and processing time delay characteristics which are introduced in this paper. Although the characteristics in geostationary orbit are slightly deteriorated as compared with those obtained from the ground test, it has been confirmed, as expected at the beginning, that the functions and performances of the switch could be realized even in space. Similar tests were performed periodically for each of performances to find the long-term deterioration characteristics of onboard equipment performances in space. Although the design life of the communication equipment provided on ETS-VIII is 3 years, periodical checking revealed that no change in the performance deemed to be a long-term deterioration was not noticed during the 4 years before completion of the experiments.

The packet switch developed has a bridge function that operates on layer 2 and is also equipped with a position registration function necessary for a mobile satellite communication system with multibeam composition. The switching function is comparatively simple, and so small size, light weight and lower power consumption features could be attained, and it could meet with system requirements on the satellite. If greater sophistication of the device to be mounted on the satellite is required in the future, the development of equipment which has more complicated switching control, and could improve network utilization efficiency, can be expected.

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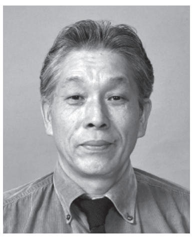

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