3-8 Onboard Packet Switch for High-Data-Rate Satellite Communications

TAIRA Shinichi, HASHIMOTO Yukio, and HAMAMOTO Naokazu

An onboard switch makes satellite communications systems with a multi-beam structure more efficient. The Communications Research Laboratory has been studying the mobile satellite communications network and developing an onboard packet switch. The switch has the function as bridges operating at the data link layer of the open systems interconnect networking model. When the switch is located in a satellite, the satellite can be regarded as the central hub. One beam of the mobile links corresponds to one segment of the network. The bridges' learning process is carried out between the beams, and the switching system builds and maintains tables with Media Access Control address information. The performance test results of the proto-flight model show that the performance of the onboard packet switch is sufficient to meet the system requirements. This onboard packet switch will be installed on the Engineering Test Satellite VIII (ETS-VIII), which is a geostationary satellite with large deployable antennas, high power amplifiers, and onboard switches for S-band personal and mobile satellite communications and sound broadcasting. After the launch of the ETS-VIII by the H-IIA rocket, various experiments will be carried out.

Keywords
Engineering Test Satellite VIII, Onboard switch, Mobile satellite communication, Packet switching

1 Introduction

Armed with onboard switching capability, a multi-beam satellite communications system offers both efficiency and flexibility. The Engineering Test Satellite VIII has two types of switches—an onboard processor for circuit switching and an onboard packet switch for packet switching [1][2]. This paper describes the basic functions of the onboard packet switch and the results of performance testing in a proto-flight model (PFM).

2 Outline of the onboard packet switch

The onboard packet switch (PKT) consists of a modulator/demodulator component (PKT-MODEM) and a baseband switch component (PKT-CONT). It has two input/output ports for feeder links and two additional input/output ports for mobile links. This configuration enables packet switching aboard the satellite. Fig.1 shows a picture of the onboard packet

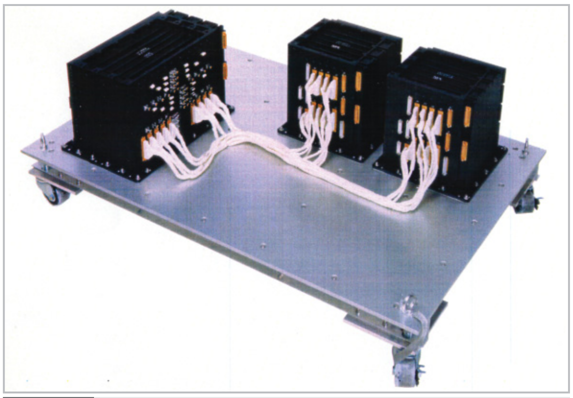


Fig.1 Photo of the onboard packet switch

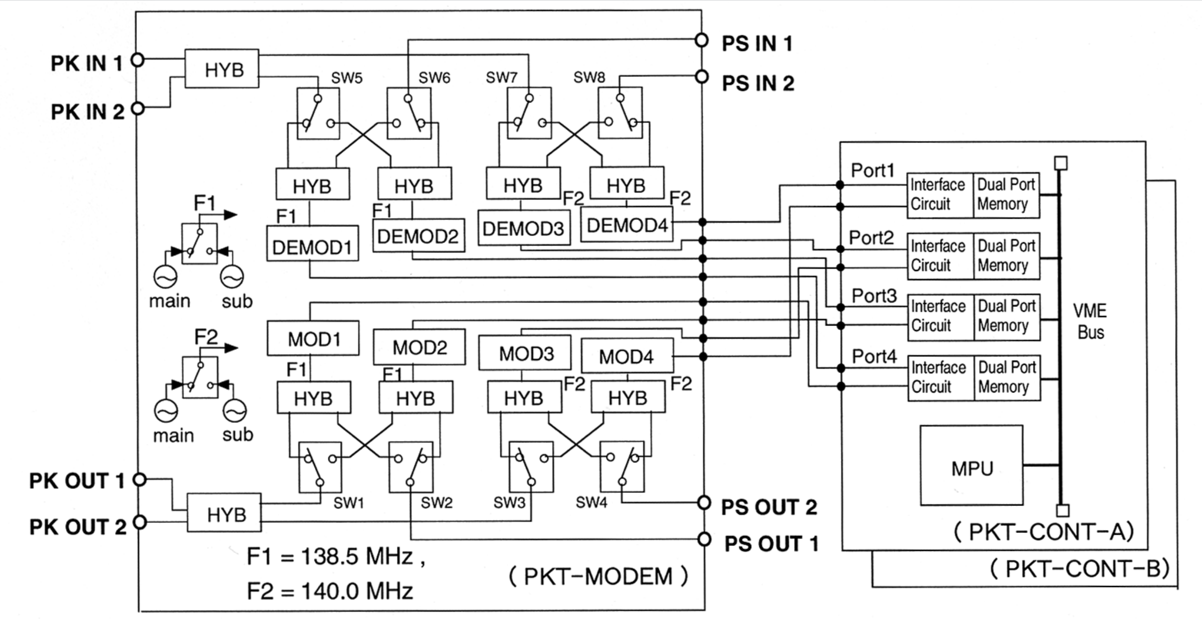


Fig.2 *Functional diagram of the onboard packet switch*

switch, and Fig.2 presents a functional diagram of this switch.

The modem component is composed of four modulators, four demodulators, IF switches, and local oscillators. The power processing unit of the modem component features redundant design, through which the sub-unit is always available to take over from the primary line. To ensure maximum reliability, the baseband switch component features full redundancy: a redundant component (PKT-CONT-B) is provided to serve as a backup for the primary component (PKT-CONT-A). In the modem component, the internal oscillators and the command processors also feature redundancy. Because the switching control data is contained in the packet, all transmitted packet signals are subject to regenerative repeating, and switching control is performed based on the provided control data. In Fig.1, the modem component is on the left and baseband switch component is on the right. These components are connected with harness cables, permitting the exchange of digital signals.

The earth station in high-data-rate communication with the packet switch is designed to exchange signals with vehicle-borne mobile earth stations and handheld mobile earth stations. Transmission EIRP (Equivalent Isotropically Radiated Power) and the ratio of the antenna gain to the receiving system noise temperature (G/T) are expected to be around 18 dBW and -22 dBK, respectively.

Table 1 shows the major specifications of the packet switch. The transmission rate is 1,024 kbps, and error correction is performed by the FEC using convolutional coding (constraint length: 7; coding rate: 1/2) and Viterbi decoding (3-bit soft decision) along with retransmission by ARQ. Packet length is normally 8 msec but can be extended to 32 msec (max.). Fig.3 illustrates the frame structure of the packet signal.

Table 1 *Major specifications of the onboard packet switch*

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

For higher channel efficiency and to enable continuous data transmission, random access is effected through a combination of the slotted ALOHA method and the packet

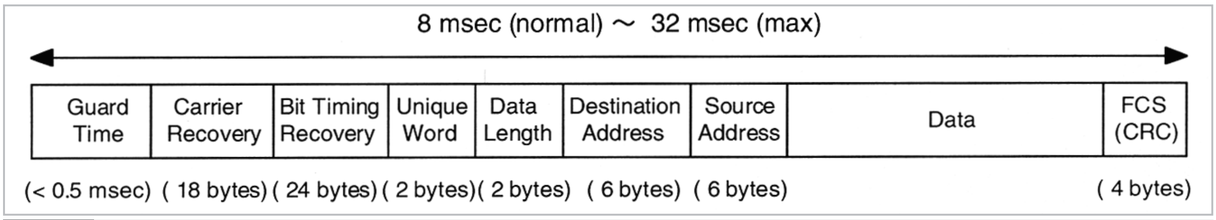


Fig.3 *Packet signal format*

reservation method. In the packet reservation method, slot reservation is performed by sending burst signals based on the slotted ALOHA method. Switching control in this case is equivalent to the Ethernet bridging function with the addition of reservation control. One input/output port corresponds to one segment of a network. The packet switch maintains and manages the MAC address table used in the data link layer. Software for switching control can be loaded from earth stations to enable experiments using various protocols. In addition, the switch offers FEC on/off switching, transmission of burst packet signals consisting of pseudo-noise (PN), and transmission of continuous waves (CW).

3 Basic performance

3.1 Bit error rate performance

An improved reverse-modulation technique is applied for the demodulator to ensure a sufficiently wide carrier range and excellent demodulating performance, even at low Eb/No ratios during packet demodulation for regenerative repeating [3].

In the performance test, we measured the bit error rate (BER), an index of the basic performance of digital modems. Fig.4 shows the relationship between Eb/No and BER. In this measurement, we changed the Eb/No ratio by varying the signal level while maintaining a constant noise level, in order to simulate actual conditions of use. The BER at an Eb/No value of 3 dBHz during FEC OFF is much worse than the theoretical projection. This is probably because the input signal level was close to the lower limit of the dynamic range of the demodulator (approximately 8 to 9 dB). In this measurement, the input signal was set

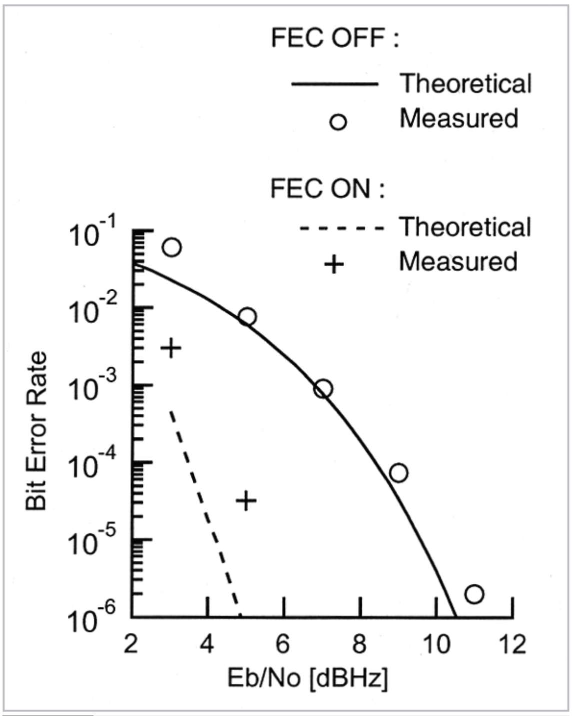


Fig.4 *Relationship between Eb/No and BER*

to a level almost in the middle of the dynamic range when the Eb/No value was 7 dB during FEC OFF. When Eb/No was 12 dBHz or higher, the signal level exceeded the upper limit of the dynamic range and thus BER increased significantly. In practical operations, we must pay attention to the dynamic range of the input signal and set levels accordingly within the satellite communications system. Fig.4 shows the test results obtained under normal temperature and normal pressure.

Additionally, we conducted similar tests at normal, low, and high temperatures in a vacuum. As a result, we obtained nearly the same results as those obtained under normal temperature/pressure, determining that the desired performance will be maintained even under the thermally harsh conditions of space.

Fig.5 shows bit error rates plotted against frequency offsets of the received packet signals. The frequency stability of the local oscillator in the frequency converter aboard the satellite is 1×10^{-6}, and that of the mobile earth station is 5×10^{-6}. If the maximum speed of the mobile station is 1,000 km/hour, the maximum frequency shift at the mobile link using the S band (2.6/2.5 GHz) becomes approximately ±20kHz. The frequency shift grows in accordance with the higher frequency in the feeder link using the Ka band (30/20 GHz). However, because the base earth station features a frequency controller on the feeder link side, the demodulators on the packet switch side can conduct demodulation within the ±20 kHz margin without performance degradation. As demonstrated in Fig.5, if the frequency shift is ±30kHz, BER does not change significantly and the necessary performance levels are met.

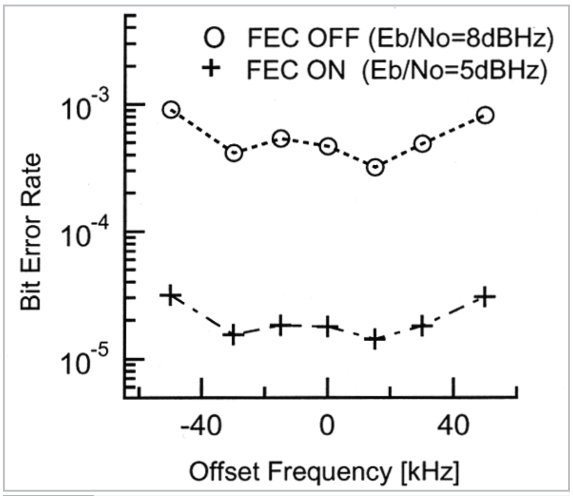


Fig.5 *Frequency offset vs. BER*

3.2 Basic performance of the baseband switch

The baseband switch has a switching function equivalent to the bridging function in the data link layer of the OSI (Open System Interconnection) networking model (the international standard for multi-vendor protocols), and another switching function equivalent to that of the switching hubs often used in ground networks, in addition to the extra function of reservation control. One input/output port corresponds to one segment of the network. The packet switch maintains and manages the MAC address table used in the data link layer. Fig.6 is a conceptual illustration of the satellite communications system using the onboard packet switch.

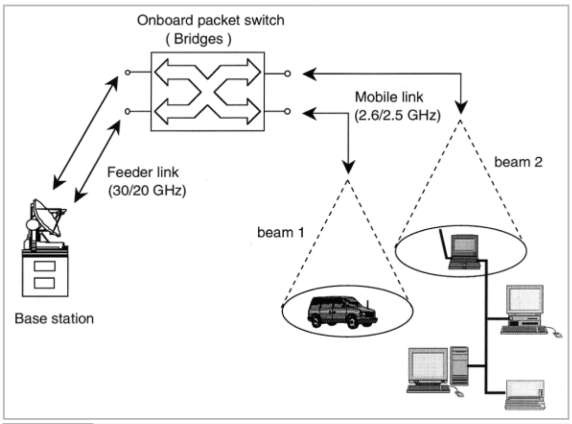


Fig.6 *Conceptual illustration of the developed communications system*

In the mobile link, one of the multiple beams corresponds to one segment of the network. In the Ethernet, signals provided to the bridge in the same segment are discarded. Meanwhile, in the current system, if the earth stations to which the input packet signals are to be sent are within the same beam, the signals are not discarded but instead are handled by the switch so that these signals can be incorporated into the same beam. The satellite knows which earth stations are within the same beam, and thus can perform the same position registration function seen in multi-beam wireless communication systems.

To ensure efficient real-time transmission, our system incorporates a packet reservation method in addition to the use of the random access mode (a mode based on the slotted ALOHA method).

Here, the packet reservation method involves a process equivalent to circuit switching. First, the earth station sends a request signal to the satellite to reserve the required time slot. The satellite, in turn, returns the time slot data to the earth station if the request is practicable; data exchange using the reserved slots is then initiated. In principle, the signal to release the reserved slots is sent from the earth station. The satellite will unconditionally release the reserved slots only when it has failed to receive signals from the earth station for a certain period of time. Fig.7 shows the packet reservation sequence.

When the satellite has received a packet signal from the earth station, it returns the acknowledgement (ACK) signal to the earth station. When conducting ARQ, it re-sends the packet signal when the earth station cannot receive this ACK signal. The satellite knows the status of the reserved slots, and the earth station also has this information, because the packet switch sends control data to the earth station every 128 msec.

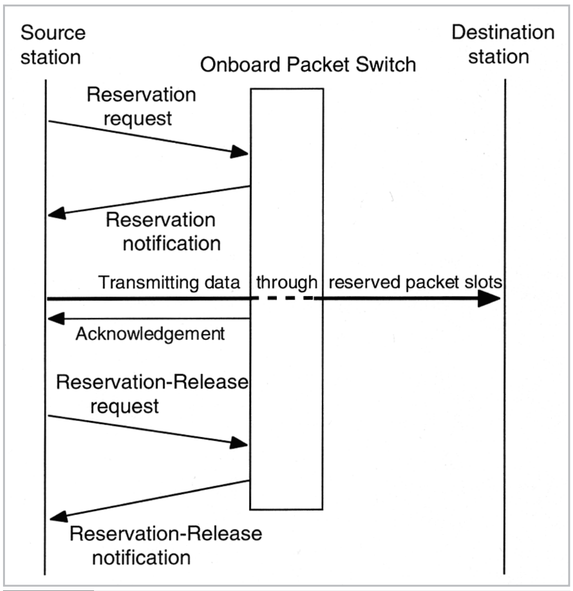


Fig.7 *Packet reservation sequence*

In the baseband switch performance test, we sent test packets in the 140-MHz band from the base earth station in a configuration in which the terminals of a base earth station and a mobile earth station were directly connected to each input/output port of the packet switch, in order to test a range of switching functions, including the bridge function. We also examined switching functions under high-temperature conditions in a vacuum to ensure that these functions worked as expected.

4 Conclusions

We presented an outline of the packet switch to be installed aboard the ETS-VIII and described basic performance tests using the proto-flight model. Through normal, low, and high-temperature tests under normal pressure and vacuum, we ensured that there were no problems in the BER of the modem unit, in control program load, or in the switching functions.

References

1 O. Takeda, S. Taira, Y. Kawakami, Y. Otsu, H. Katagiri, and T. Kumagai , "Research and Development of On-Board Processor for Advanced Mobile Satellite Communications", 17th AIAA International Communications Satellite Systems Conference and Exhibit, AIAA-98-1311, Feb. 1998.

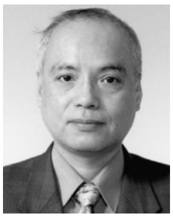
2 S. Taira, Y. Matsumoto, S. Hama, and N. Hamamoto, "An Onboard Packet Switching System for the Mobile Satellite Communication Network", 49th International Astronautical Congress, IAF-98-M.3.03, Sep. 1998.

3 M. Yoneda, Y. Tsuchihashi, O. Takeda, S. Taira, and N. Hamamoto , "The Characteristics of Digital Modulation and demodulation for Engineering Test Satellite-VIII (ETS-VIII) On-Board Packet Switch", 19th AIAA International Communications Satellite Systems Conference and Exhibit, Apr. 2001.


TAIRA Shinichi

Leader, Mobile Satellite Communications Group, Kashima Space Research Center, Wireless Communications Division

Mobile Satellite Communication, Switching System, Onboard Equipment


HAMAMOTO Naokazu

Research Supervisor, Wireless Communications Division

Satellite Communication Engineering


HASHIMOTO Yukio

Senior Researcher, Broadband Satellite Network Group, Wireless Communications Division

Satellite Communication