4-7-5 Development of a OBP/PKT Communication Terminal

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A developmental trial was carried out of a communication terminal to be used for satellite communication experiments using the signal-processing (OBP) and packet-switching (PKT) equipment onboard ETS-VIII. The OBP and the PKT are the satellite voice-communication equipment and data-communication equipment, respectively, for mobile satellite communications. They have different transmitting speeds and communication protocols from each other. The terminal developed has two functions: (1) to operate as a communication terminal for the OBP, and (2) to act as a terminal for the PKT. To accomplish these two different functions using the same terminal, digital signal processing techniques were adapted from the area of modulation and demodulation processing in the base-band to the process of frequency conversion between the base-band and inter-medium frequency band. These signal-processing techniques were performed using integrated-circuit semiconductors for digital frequency conversions and software signal processing with a high-speed digital signal processor. This trial showed that it is feasible to build a unique, compact communication terminal (A4 size without the RF sections) that can be operated for both types of communication systems.

Keywords
Satellite communication, Engineering Test Satellite VIII, Onboard signal switching equipment, Communication terminal, Digital Signal Processing

1 Introduction

The Engineering Test Satellite VIII (ETS-VIII) will be equipped with devices to switch communication signal routes, enabling single-hop connection (i.e., bypassing the base station) between users within the same beam or across different beams. Two types of onboard switching devices have been developed, featuring different transmission rates and methods. One type consists of signal-processing equipment for voice communication (OBP) [1] [2], while the other involves the use of an onboard packet-switching device for mobile data communication (PKT) [3] [4]. The diagram in Fig.1 shows an overview of satellite communication systems based on these two types of onboard signal-switching devices.

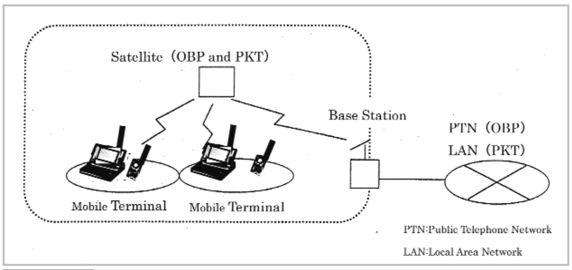


Fig.1 *Overview of satellite communication with OBP and PKT*

These two onboard signal-switching devices have been developed for completely independent purposes and have no mutual signal connections. The respective radio interfaces and communication protocols also differ significantly. One device must be switched off while the other is in operation, due to restrictions in the power resources of the satellite and relay signal routes. Thus it is generally assumed that OBP and PKT communication terminals must be developed and used separately.

However, recent advances in digital signal-processing techniques have enhanced software-based processing of various communication signals. These techniques have enabled the construction of a communication terminal prototype capable of treating both OBP and PKT data. This terminal applies digital signal processing to the full extent possible to adapt common hardware to different transmission rates and communication protocols. Such a device can operate as an OBP or PKT communication terminal through software switching via external interface.

This report presents a communication terminal prototype developed with both OBP and PKT communication functions (the OBP/PKT communication terminal). This communication terminal employs IF-band (140 MHz) input and output signals. Applying the latest high-performance LSI (large scale integrated circuit) for digital signal processing, the dual-communication terminal is relatively compact (corresponding approximately to A4 size). Simply connecting the terminal through a LAN to a personal computer (PC) provided with a general-purpose browser also enables terminal control (terminal start up, parameter modification, call-in and -out requests in OBP mode, etc.). The same PC can run general applications at the same time, including Internet connection in PKT mode. In section 2 of this report we discuss the hardware requirements for common functions; in Section 3 we will outline required equipment configurations, and Section 4 will present a review of signal processing for modulation/demodulation and communication control.

2 Hardware requirements

Table 1 lists the major OBP and PKT specifications side-by-side to clarify the required characteristics of a prototype OBP/PKT communication terminal. Both have the same basic function: to select a route within a beam or across beams according to user request via onboard computer. Here, OBP is for voice communication between portable terminals and uses multi-carrier TDMA (time division multiple access) with a low information rate of 5.6 kbps per channel due to the limitations in transmission and reception capabilities of the portable terminals. On the other hand, PKT is for relatively rapid data communication with mobile terminals, such as those installed in automobiles, using the packet transmission method (with a transmission rate of 1.024 Mbps per carrier).

Based on these specifications for the signal-switching devices, the required characteristics of an OBP/PKT communication terminal are as follows.

(1) Support for different channel frequencies and different channel spacing (50-kHz spacing in OBP mode and 1.5-MHz spacing in PKT mode)

(2) Support for different transmission rates (70 kbps in OBP mode and 1024 kbps in PKT mode) and different access methods (multi-carrier TDMA in OBP mode and slotted ALOHA in PKT mode). OBP mode should support simultaneous reception in two signal channels at different frequencies, for separate reference and communication signals.

(3) Support for different connection control protocols

(4) Support for different uses (voice communication in OBP mode and data communication in PKT mode)

On the other hand, the following radio parameters are common to both OBP and PKT modes.

- Modulation/demodulation methods are the same (π/4-shift-QPSK and coherent detection).
- Both receive burst signals with an unmodulated preamble signal header (The lengths of the preambles are different for OBP and PKT modes.).
- Both use the same error-correction method (Convolutional coding with a rate of 1/2 and

Table 1 *Major specifications of the ETS-VIII onboard signal-switching equipment*

	Onboard Signal Processing Equipment (OBP)	Onboard Packet Switching Equipment (PKT)
Access method	Multi carrier TDMA	Slotted ALOHA
Modulation	π/4-shift-QPSK	
Demodulation	Generative mode: Coherent Detection Non-generative mode: Base-band Filtering	Coherent Detection
TX & RX Filter	Root Nyquist (Roll Off=50%)	
Transmission Rate	35k symbol/sec	512k symbol/sec
FEC	Convolutional Coding R=1/2, K=7,	
Satellite Beam	Service Link (S-band) 3 Feeder Link (K-band) 1	Service Link (S-band) 2 Feeder Link (K-band) 1
No. of Carrier/Beam	Non-generative mode: 50 Generative mode: 16	1
Channel Separation	50kHz	1.5MHz
Channel Capacity	5. 6kbp voice 5ch / Carrier 32kbpsDate 1ch / Carrier	4.8kbps～64kbps/user
Channel assignment	Demand assign	Random or Reserved packet
IF frequency	138.5 ～ 141 MHz	
Allowable Freq. error	less than 10 % of Symbol rate	

constraint length of 7).

- The roll-off factor of the transmission and reception root Nyquist filter is 0.5 for both.

The hardware configuration of the OBP/PKT communication terminal prototype must take all of these features into consideration. As the respective signal-switching devices aboard the ETS-VIII will never operate simultaneously, the communication terminal is not required to perform the two functions simultaneously. The input and output frequencies for this terminal are set in the IF band (140-MHz band). Satellite communication with this terminal requires that the terminal be connected to a separate portable earth station; specifically, a general-purpose earth station equipped with frequency-conversion functions for the 140-MHz and S-band, transmission and reception functions for RF signals, and an antenna.

3 Basic configuration

Fig.2 shows the basic configuration of the OBP/PKT communication terminal designed based on the requirements discussed in the previous section. Table 2 shows the specifications of the terminal. Fig.3 shows the external appearance of the terminal. Broadly speaking, the terminal consists of an analog processing unit, a digital processing unit, and equipment for external connection. These functions are discussed below.

3.1 Analog processing unit

The analog processing unit converts the 140-MHz IF to a second IF using an ordinary mixer. Here, bandpass filters for the required

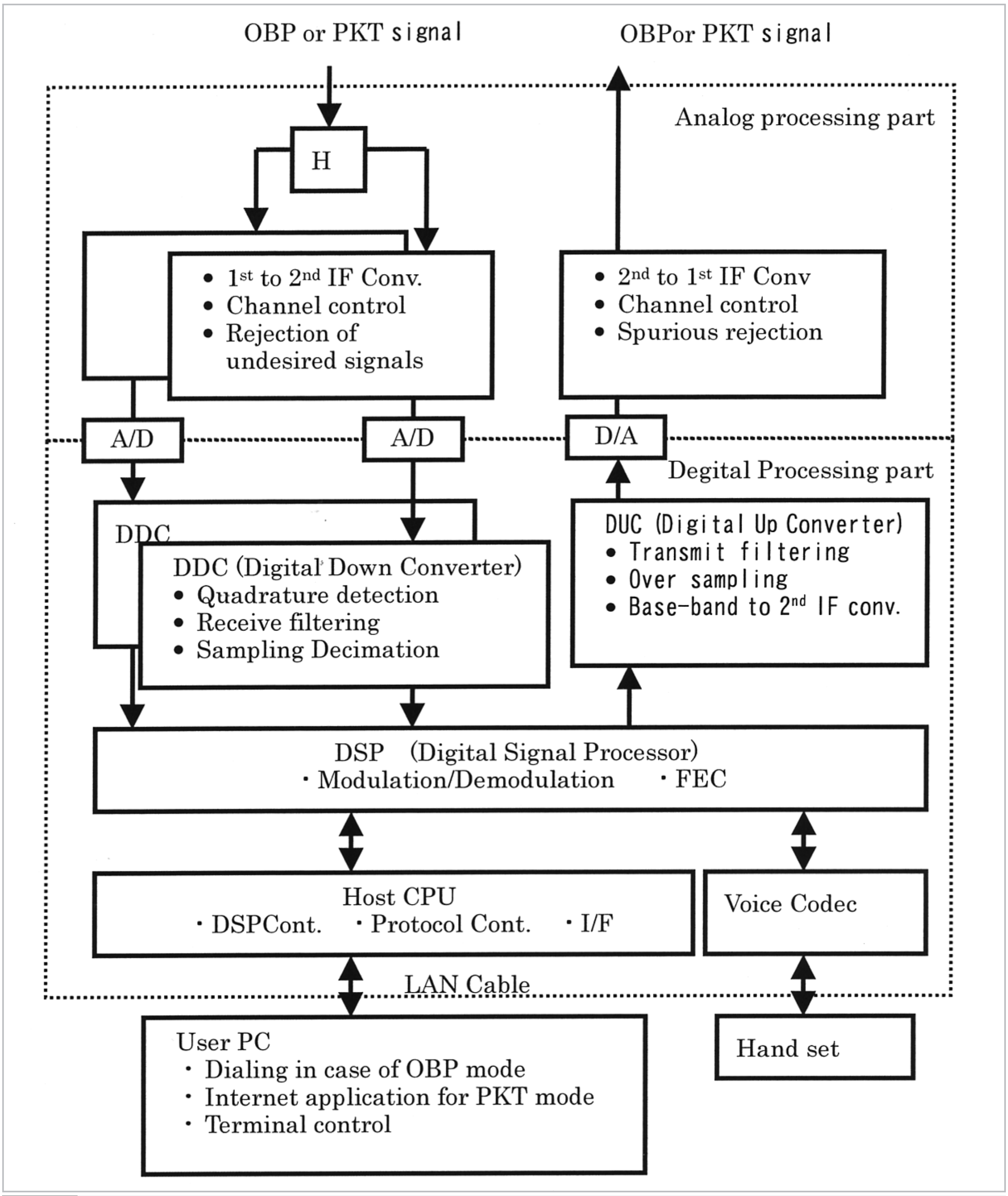


Fig.2 *Basic configuration of the OBP/PKT communication terminal*

bands are inserted before and after the mixer to remove spurious signals and to limit receiver noise. Level adjustment is also conducted using an attenuator (ATT) that can be externally controlled. As the transmission bandwidths differ between the OBP and PKT modes (OBP: 35 ksps, PKT: 512 ksps), custom bandpass filters are prepared for each; an analog switch is used to toggle between them. To provide for the different frequencies and channel spacing discussed in (1) of the previous section, the frequency of the local oscillator is controlled to establish the necessary channel frequency. This local oscillator uses a 12.8-MHz TCXO (temperature controlled crystal oscillator) as the original oscillator and fea-

Table 2 Specifications of the OBP/PKT communication terminal

	OBP mode	PKT mode
Modulation	π/4-shift-QPSK	
Symbol rate	35ksps	512ksps
1st IF	138.0MHz～140.5MHz	
Input Level	-22dBm nominal (-32dBm～-16dBm variable)	-10dBm nominal (-20dBm～-4dBm variable)
Output Level	-23dBm～-7dBm variable	-20dBm～-4dBmvariable
TX 2nd IF	51.76MHz	
RX 2nd IF	10.52MHz and 10.7MHz	10.7MHz
Frequency Control Step	10kHz	
Voice Coded	PSI-CELP	—
TX 2nd IF Sampling Freq.	134.4MHz	131.072MHz
RX 2nd IF Sampling Freq.	32.760MHz	32.768MHz
Digital Up Converter	AD9857 including D/A	
Digital Down Converter	AD6620	
RX A/D Converter	AD6644	
Digital Signal Processor	TMS320C6416 400MHz (with Viterbi Decoding Co-processor)	
Host Computer	GX1 - 300MHz、128MByte SDRAM	
External Interface	10Base-T	
Size	290 x 190 x 50 (mm)	

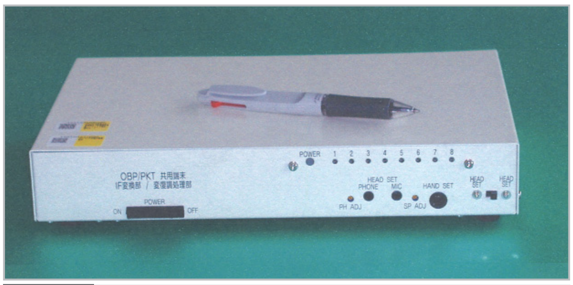


Fig.3 External appearance of the OBP/PKT communication terminal

tures a PLL (phase lock loop) to control the oscillation frequency externally in 10-kHz steps. The analog and digital processing units are connected with A/D or D/A converted signals (A: Analog, D: Digital) in the second IF band.

3.2 Digital processing unit

The main components of the digital processing unit are a digital up converter (DUC), a digital down converter (DDC), a digital signal processor (DSP), a built-in host computer (CPU), a voice codec unit, a field programmable gate array (FPGA) constituting the peripheral circuits for the DSP and CPU, and clock oscillators for the various LSIs. The following discusses the functions of each component and the handling of requirements (2)–(4) indicated in the previous section.

(1) DUC

The DUC (AD9857 Digital Up Converter LSI, Analog Devices, or “AD”) conducts the required over-sampling and quadrature modulation of the N sample/symbol (N=16 in OBP mode and N=4 in PKT mode) transmission digital baseband signals that are generated in the DSP and processed through an output filter. The DUC then outputs D/A converted frequency signals in the second IF band. Over-sampling of the second IF signals (51.76 MHz) in OBP and PKT modes is conducted as described below. A single LSI conducts quadrature modulation and frequency conversion of the modulation signals at different transmission rates by switching the over-sampling rates in the DUC between the OBP and PKT modes.

OBP: 16 samples/symbol (560 kHz) × 240 = second IF sampling frequency (134.4 MHz)

PKT: 4 samples/symbol (2048 kHz) × 64 = second IF sampling frequency (131.072 MHz)

(2) DDC

The DDC (AD6620 Digital Down Converter LSI, AD) conducts pseudo-quadrature detection, reception filtering (root cosine roll-off with a roll-off factor of 0.5), and sampling decimation (up to 4 samples/symbol) for the A/D converted second IF digital signals received (OBP: 10.52 MHz and 10.7 MHz; PKT: 10.7 MHz). The ratio of sampling decimation in the DDC is set as follows for the OBP and PKT modes:

OBP: second IF sampling frequency (32.7 MHz)/234 = 140 kHz (4 samples/symbol)

PKT: second IF sampling frequency (32.768 MHz)/16 = 2048 kHz (4 samples/symbol)

(3) DSP

The DSP (TMS320C6416 digital signal processor, Texas Instruments, or "TI") generates the digital baseband signals to be transmitted to the DUC and demodulates the digital baseband signals received from the DDC. This 32-bit fixed-point processor can conduct a maximum of eight operations simultaneously using two sets of four types of built-in arithmetic registers, and features 3200-MIPS performance (when operating at a clock frequency of 400 MHz).

Both OBP and PKT modes use π/4-shift-QPSK for modulation/demodulation, coherent detection of burst signals for demodulation, and Convolutional coding for error-correction coding. These common modulation and demodulation processes can apply the same techniques for the signal processing algorithm if the sampling rates per symbol are the same, even though the transmission rates may be different. Thus, the DSP software codes for the OBP and PKT modes have much in common, simplifying software development. Further, the Viterbi decoding DSP hardware function is used for Convolutional coding error correction, which also reduces the software processing load.

(4) Built-in host computer

The host computer is a general-purpose PC module (PCM-3350 F by Advantech, with a National Semiconductor (NS) onboard CPU: GX1-300 MHz; 128 MB of SDRAM system memory). The OS is Linux. This built-in host computer transfers the signal-processing software code to the DSP, controls the DSP operation modes, sends transmission data to the DSP, acquires demodulation data from the DSP, processes the radio control protocol corresponding to the onboard signal switching equipment, provides network processing to transmit the Internet protocol to the satellite network (bridge function), and processes the external interfaces. This host computer is also equipped with flash memory for storage of the control software.

(5) Voice codec

Voice communication in the OBP mode uses the PSI-CELP voice codec board (MPD-200, Japan Kyastem, with TI's onboard DSP TMS320 VC 5420 for voice coding and decoding). This board transports the coded voice data to the DSP and decodes the voice data demodulated in the DSP.

(6) Peripheral circuits

The A/D converter, DUC, DDC, and other devices described above require different driving clocks at frequencies that also differ between OBP and PKT modes. Thus, several direct digital synthesizer LSIs with variable oscillating frequencies (DDS: AD9851, AD) generate the necessary clock frequencies for each LSI. The FPGA, which processes signals between the DSP and DUC or DDC, also provides further functions, including additional filtering.

3.3 Externally connected equipment

To use the OBP/PKT communication terminal, the user must have a PC with installed browser software. The built-in host computer is assigned an exclusive IP address and functions as a server. When the user accesses the host computer, the browser displays buttons permitting control of the OBP/PKT terminal. Terminal control includes switching between the OBP and PKT modes, modification of parameters for each mode, dialing of the telephone number in the OBP mode, and loading software to the onboard signal switching equipment in administrator mode.

When the OBP/PKT communication terminal is used as a mobile station in PKT mode, the user PC is also used to operate general-purpose applications (e.g., Internet connection and sending and receiving of email). Here, another OBP/PKT communication terminal connected to a PC with server functions or to a router connected to a LAN is assumed to be used at the other end of the communication link.

4 Outline of signal processing

4.1 Demodulation processing by DSP

The radio signals used for OBP and PKT are burst π/4-shift-QPSK signals, with unmodulated and clock patterns added to the header. The receiver demodulates the signals by coherent detection. Coherent detection for these signals requires high-speed carrier-recovery and clock-recovery processes. Generally, there are two types of digital signal processing: storage-type signal processing that stores one burst of sample signals before demodulation, and real-time processing, in which the received signals are successively demodulated. Storage-type signal processing enables complex operations that cannot be performed with real-time processing, such as FFT and time reversal. However, this type of processing has certain disadvantages: it requires significant memory and entails marked processing delays in voice communication. On the other hand, real-time processing allows for signal demodulation with limited memory and minimal processing delay, reducing the signal-processing delay in voice communications in OBP mode. Real-time processing has thus been adopted in the prototype terminal.

Rapid carrier recovery based on the LERF method is available for real-time processing [5], enabling detection and high-speed carrier recovery of input signals with large frequency offsets and low C/N (carrier to noise) ratios. This method integrates adaptive filtering using an infinite impulse response filter into an inverse-modulation feed-forward carrier recovery circuit. Fig.4 shows the configuration of this circuit. This method also has a capability of timing detection of the incoming preamble part of OBP or PKT signals and completes carrier recovery processing during the course of the preamble part. The computer simulation in reference [5] results in carrier recovery that is complete within several tens of symbols at a C/N of 6 dB for a signal with a frequency offset that is 5% of the symbol rate.

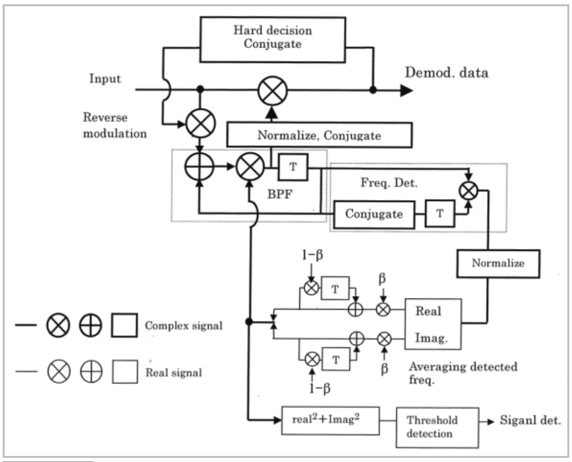


Fig.4 Carrier recovery system using the LERF method

4.2 Communication control protocol processing

The OBP/PKT communication terminal conducts communication control processing based on the communication protocol and control specifications [6] [7] of the OBP and PKT onboard signal switching equipment, with the host computer controlling the peripheral circuits, including the DSP. The various communication controls are outlined below.

(1) OBP communication control

Directly after startup, the terminal receives a BCCH signal (the OBP frame reference signal) from the satellite and performs frame synchronization. Next, the terminal conducts subscriber registration (registration of the subscriber's area code and telephone number in the onboard signal-switching device) and positioning registration (registration at the satellite of the subscriber's position corresponding to a satellite beam area to prepare for ordinary telephone call requests. In response to a call request from a user (caller process) or from the satellite (calee process), the terminal establishes the satellite link according to the following procedure and enters voice-communication mode.

- Establishment of a link channel

The terminal establishes a link to exchange control information between the onboard signal switching equipment and the terminal using a specific slot in the specified frequency channel of the OBP frame. Here the transmission timing is adjusted based on the transmission timing information included in the BCCH.

- Establishment of a service channel

The onboard signal switching equipment allocates a service channel for voice communication through the established link channel.

- Call phase

The terminal conducts point-to-point communication with a remote station using the service channel. OBP operates in non-generative mode when used for communication between a mobile terminal and the base station. In this mode, the terminal and the base station are directly connected to each other and are synchronized to the OBP frame. On the other hand, OBP operates in generative mode when used for communication between two mobile terminals connected via an S-band service link. In this mode, the remote station connected to each terminal is in fact the onboard satellite modem.

- Call termination phase

The terminal re-establishes the link channel and notifies the onboard signal switching equipment of disconnection after termination of the call.

Additional modes are available: administrator mode, for modifying the parameters of the onboard signal switching equipment and for loading network control software, and fixed-test mode, in which the connection status is fixed.

(2) PKT communication control

Network control is simpler in PKT mode than in OBP mode, as the PKT mode employs slotted ALOHA packet communication. First, the terminal receives the reference signal transmitted periodically from PKT and synchronizes the PKT frames. The terminal can then transmit data to the address of the remote station. Here the address corresponds to the MAC (Media Access Control) address exclusively designed for the PKT system and attributed to each terminal. The onboard signal switching equipment features an onboard mapping table including the MAC address and the user beam port, to perform switching between the beams. This function corresponds to that of bridges used in LANs on the ground. On the other hand, Internet applications in the general-purpose PC connected to the terminal perform communication based on the IP address. Thus, the OBP/PKT communication terminal needs to feature a conversion routine between the MAC and the IP addresses (bridge function) or it must function as a gateway (router function). The device developed in the current study features the bridge function.

The user can choose between random or reserved modes when using the satellite link.

- Random mode

The random mode sends the packet signal to an arbitrary slot in the random slot area. When the packet signal collides with another packet signal, necessary measures are taken. (When the satellite receives the signal normally, this is confirmed through reception of the partial echo signal.)

- Reserved mode

Reserved mode communication entails the attribution of a specific slot to each minor or major PKT frame. This mode avoids packet collision. When the user earth station employs the reserved mode, the terminal sends a reservation request packet before transmitting data, confirms the reservation information from PKT, and initiates communication.

The choice between random or reserved mode is currently the user's. However, specific criteria for selection has yet to be established; accordingly, we need to consider a method of selecting the optimal mode according to the specific application.

5 Summary

A communication terminal has been developed for OBP and PKT aboard the ETS-VIII. This terminal adopts digital signal processing for all signal processing at or below the IF. The terminal features dual communication functions in its approximately A4-sized body. Performance tests will be conducted. After the launch of the ETS-VIII, this terminal will be used in outdoor communication experiments for the onboard signal-switching equipment.

As a final note, we would like to express our gratitude to Spectra Co-op for their assistance in the construction of this terminal.

References

1 Y. Kawakami, S Yoshimoto, Y Matsumoto, T Ohira, and T. Ide, "S-bandMobile Satellite Communications and Multimedia Broadcasting Onboard Equipment for ETS-VIII", IEICE Trans Vol.E82-B, No. 10 Oct. 1999.

2 Y. Hashimoto, K Nakajima, Y Kawakami, O Takeda, Y Tshchihashi, and S Senba, "Study of an On-Board Processor for Mobile Satellite Communication Experiments of ETS-VIII", 22nd ISTS Conf. Record, ISTS2000-i-04, May, 2000

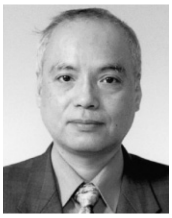
3 S. Taira, T. Ide and S. Hama, "Development of an Onboard Packet Switch for the Mobile Satellite Communication System", AIAA Conf. Record. AIAA-2000-111, Apr. 2000.

4 M. Yoneda, S. Uno, O. Takeda, S. Taira, and N. Hamamoto, "Demodulation Characteristics of the Onboard Packet Switch for the ETS-VIII", Tech. Report of IEICE, A-P2000-88, SANE2000-65, RCS2000-111, pp.43-48, Oct. 2000.

5 N. Hamamoto, Y. Hashimoto, T. Ide, and M. Sakasai, "Signal Detection and Frequency Estimation for LEO Communication Systems", Review of the Communications Research Laboaratory, Vol.44, Nos.1/2, pp.33-45, March/June 1998.

6 "Management Control Specification of Onboard Switching Equipment", Advanced Space Communications Research Laboratory, 2002.

7 "Protocol Specification of Packet Onboard Switching Equipment", written by Communications Research Laboratory, 2002.



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