3-7 The On-Board Processor for a Voice Communication Switching

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We developed the on-board processor (OBP) used for voice communication switching of mobile satellite communication systems. It uses multi-carrier time division multiple access to support high-capacity voice communication systems. Most functions (filtering, switching, carrier composition, and regeneration) are performed by digital signal processing; ASIC technology is used to reduce device size and power consumption. The switching function is controlled autonomously by software (call management, user management, and OBP management, as well as by using statistical and logistical data). We tested the interface functions of the OBP after it was installed on engineering test satellite VIII (ETS-VIII) and determined that the OBP proto-flight performance test results met the system requirements.

Keywords
Satellite communication, Regenerative transponder, On-board processing, Digital signal processing, Hand-held Terminal

1 Introduction

Mobile satellite communications were previously restricted to vehicle-borne and other types of mobile stations, due to limited satellite capabilities. Handheld terminals—such as the cell phones used in ground-based wireless systems—were thus unavailable. However, with the recent commercialization of the Iridium system (using LEO satellites) and the Thuraya system (using geostationary satellites), the use of such handheld terminals is now a reality.

In Japan, the government has led an initiative to develop a similar mobile satellite communications system using geostationary satellites and handheld terminals [1]. At the heart of this system is a novel onboard voice communications switch, to be installed aboard the Engineering Test Satellite VIII (ETS-VIII) [2]. This switch, featuring a self-controlled switching function and a regenerative transponder, involves the adoption of a circuit primarily designed to process digital signals, referred to as the “on-board processor,” or “OBP.”

This paper will describe the applicable specifications, structure, communication control protocol, and performance test results.

2 Outline of the mobile satellite voice communications system

Because any satellite enabling the use of handheld terminals must offer advanced capabilities, the ETS-VIII will feature an onboard S-band large deployable reflector 13 meters in diameter. Meanwhile, the OBP will reduce the burden on handheld terminals and ground base stations by incorporating regeneration and self-controlled switching functions.

Fig.1 is a schematic illustration of the mobile voice communications system using the ETS-VIII. The 20/30- GHz feeder link is a channel for connection to the ground base station. The base station connects handheld terminals to the public network and controls

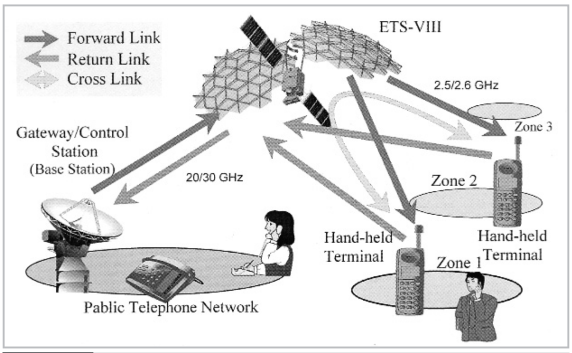

Fig.1 Conceptual illustration of the mobile voice communications system

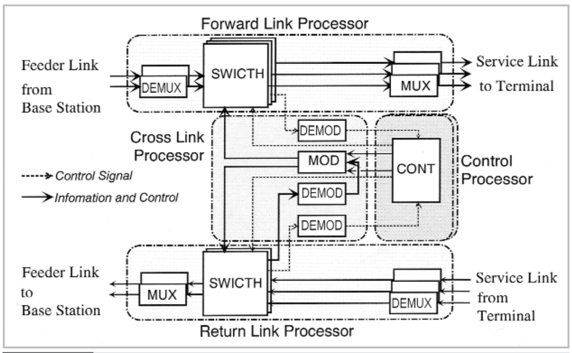

Fig.2 OBP structure

the channel capacity for each communication area, to complement the self-controlled switching function. The 2.5/2.6- GHz service link is the channel for handheld terminals, and the ETS-VIII features three dedicated beams for this purpose.

The channel connecting handheld terminals to the public network features a forward link from the ground base station to a handheld terminal and a return link from a handheld terminal to the ground base station. A cross link for regenerative repeating is used in communication between handheld terminals.

3 Structure and main specifications

The OBP consists of a forward link processor that handles forward link signals, a return link processor that handles return link signals, a cross link processor that conducts regenerative cross link repeating and also modulates/demodulates communication control signals, and two control processors that control communication and the OBP itself [3]. Fig.2 shows the structure of the OBP.

The feeder link RF line and the service link RF line establish connections via a 140-MHz IF. Three channels are used for connection to the service link RF line, corresponding to three beams. Two channels are used for connection to the feeder link RF line, with a communication capacity corresponding to the three beams of the service link. It is possible to use either of these lines individually.

Table 1 shows the main specifications of

Table 1 OBP main specifications

Electronically	
Frequency band	
Mobile link	2.5 / 2.6 GHz
Feeder link	20 / 30 GHz
Beam number	mobile link: 3 feeder link: 2 (simultaneously)
IF frequency band	140 MHz
Bandwidth	mobile link: 2.5 MHz / beam feeder link: 4 MHz / beam
Multiple Access Method	Multi carrier TDMA
Carrier spacing	50 kHz
Information Type	Voice and data
Information rate	voice: 5.6 kbps, data: 32 kbps
Transmission rate	70 kbps
Modulation	π / 4 shift QPSK
Forward error correction	Both up and down link Convolutional coding and Viterbi decoding 3 bit soft decision Constraint length: 7 Coding rate: 1/2
Process delay time	less than 0.1 sec
Carrier Separation filter	+ / - 20.5 kHz at 3 dB
Attenuation	more than 35 dB at +/- 29.5 kHz
Mechanical	
Vibration	19.7 Grms
Temperature	-20 to 50 degrees C
Total dose radiations	1*10E6 rad
Weight	90 kg
Maximum supply power	401.15 W

the OBP system. The OBP conducts π/4-shift QPSK decoding at 70 kbps and error correction using the 1/2-rate convolutional coding/Viterbi decoding method. The OBP can send voice data at 5.6 kbps per carrier (through five channels by MC-TDMA with frequency intervals of 50 kHz) and can also send data at 32 kbps, per carrier.

At the design stage, the bandwidth of each port was determined to be 5 MHz and the number of switchable channels was set to 1,000 or more for voice data. Since the S bandwidth of the ETS-VIII is 2.5 MHz, the service link transmission capacity was equivalent to 720 channels of voice data. In order to reduce spurious S-band radiation toward neighboring satellites, the bandwidth of the output circuit on the service link side of the forward link processor and return link processor was limited to 4 MHz. Because the same circuit has been employed on the feeder link side, 880 channels of voice data are available. The cross link processor that performs regenerative repeating can modulate/demodulate 32 waves, allowing for 160 channels of voice data. However, since 8 waves are used in exchanging control signals, 120 channels of voice data are available for communication.

The OBP converts the communication band directly to the base band by quasi-quadrature detection, digitizes the signals, and then samples, switches, modulates/demodulates, and combines the communication signals using a digital signal circuit employing numerous large-scale gate arrays or field programmable gate arrays (FPGAs). Table 2 shows the number of application-specific integrated circuits (ASICs) manufactured from gate arrays.

The control processor software provides communication using channel pre-assignment. The normal operating software, featuring self-controlled switching, is downloaded via network after the OBP has been activated, so the software can be modified as necessary.

The OBP weighs about 90 kg, and its maximum power consumption is approximately 400 W, depending on the operation mode and the number of beams employed.

Table 2 Number of ASICs used

Forward/Return link processor	
Poly phase filter	40
FFT/IFFT	45
Switch	5
Cross link processor	
Demodulator	4
Viterbi decoder	16

5 Forward and return link processors

Fig.3 shows a block diagram of the forward link processor. Both the forward link processor and the return link processor have demultiplexers (for quasi-quadrature detection and for splitting waves), a switch, multiplexers (for wave combination and quadrature modulation), an interface, and a power supply. The number of demultiplexers and multipexers vary with the number of input/output ports.

The quasi-quadrature detector circuit converts the 140- MHz IF signals into two quadrature base-band signals using 140- MHz local signals. The 2- MHz-band quadrature signals are digitized with an analog-digital converter (ADC). This ADC is an 8-bit processor with a 48 dB dynamic range.

The demultiplexer circuit adopts a polyphase FFT circuit in order to divide the 4-MHz MC-TDMA signals at intervals of 50 kHz of the carrier wave. The switching circuit

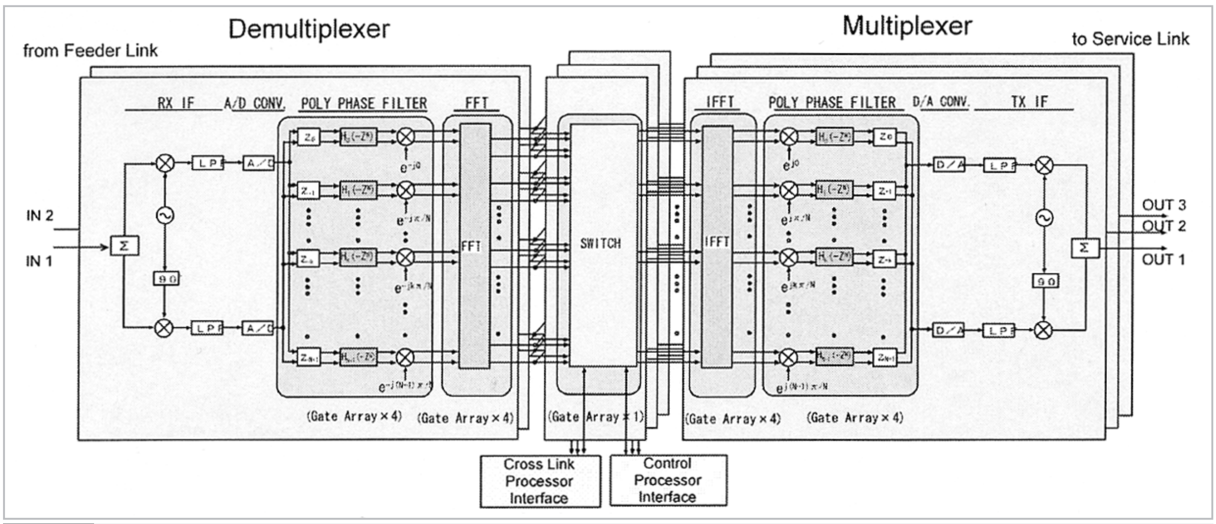

Fig.3 Block diagram of the forward link processor

receives signals from the demultiplexer and outputs them to the multiplexer or cross link processor, subject to control by the control processor. The signals from the cross link processor are handled by the switch in the same manner. Upon activation, the switch is set to the channel pre-assignment state. The multiplexer converts the received signals into 2- MHz base-band quadrature signals using the IFFT and poly-phase filter to conduct reverse calculation for the demultiplexer. The quadrature signals pass the base-band filter suppressing unnecessary waves (i.e., those higher than 2 MHz). The quadrature modulation circuit converts the 2-MHz quadrature signals to analog signals with a digital-analog converter (DAC) and then conducts quadrature modulation using 140- MHz local signals.

The interface sends and receives the control signal and regenerative repeating signal to and from the cross link processor and receives the control signal from the control processor. The power supply conducts primary power conversion from DC 100-V bus power to DC 24 V. The voltage required for each circuit is generated by a secondary power supply installed in each substrate.

Because there are two or three demultiplexers or multiplexers, no redundancy is necessary in the circuit. The interface circuit has two lines; the line connected to the control processor is the operative one. The 140-MHz local signal is used in the quasi-quadrature detection circuit and the quadrature modulation circuit, and each of these circuits features a main unit and a redundant unit; the signal can be switched between these units by the appropriate command. The power supply also features a main unit and a redundant unit; selection is performed via a command arising upon OBP activation.

6 Cross link processor

Through the interface, the cross link processor communicates and exchanges control signals with the forward link processor and return link processor. Fig.4 shows a block diagram of the cross link processor, consisting of demodulators, modulators, an interface, and a power supply. The demodulators and modulators handle 32 waves, 8 of which are used to exchange control signals.

There are four demodulation and modulation units. The circuit has been reduced in size by time-division multiplexing of the 8-wave signals in each unit. The demodulation unit consists of a $\pi/4$-shift QPSK demodula-

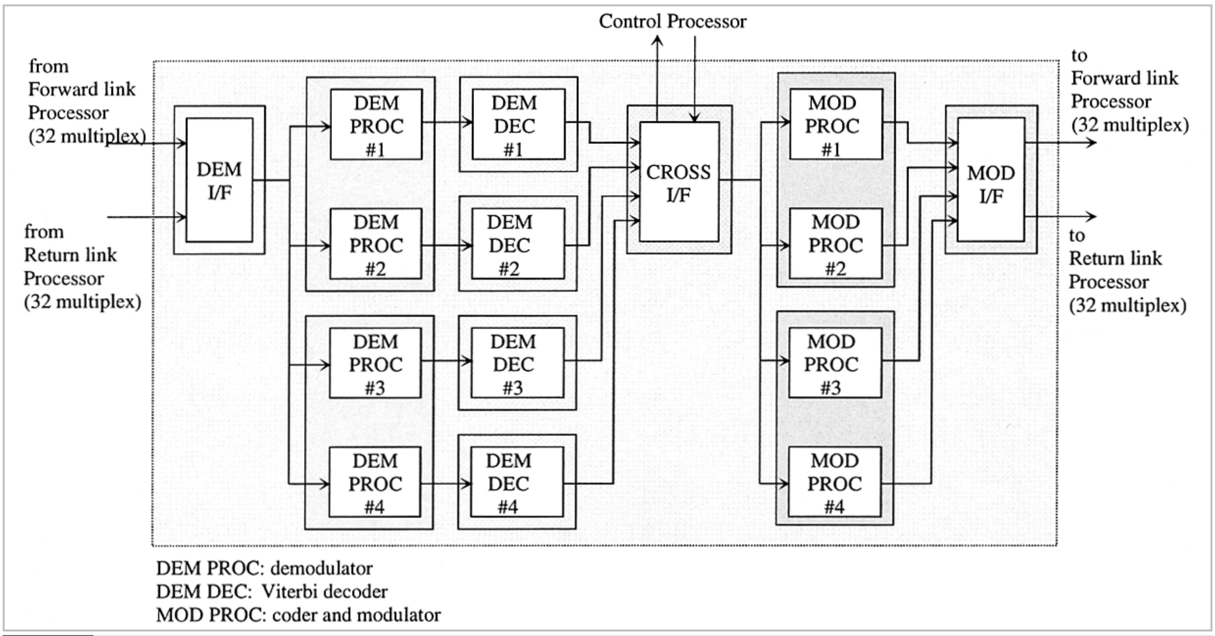

Fig.4 Block diagram of the cross link processor

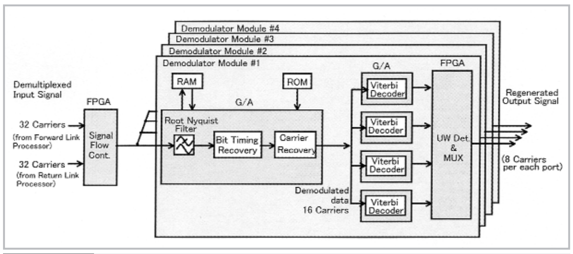

Fig.5 *Functions of the demodulation circuit*

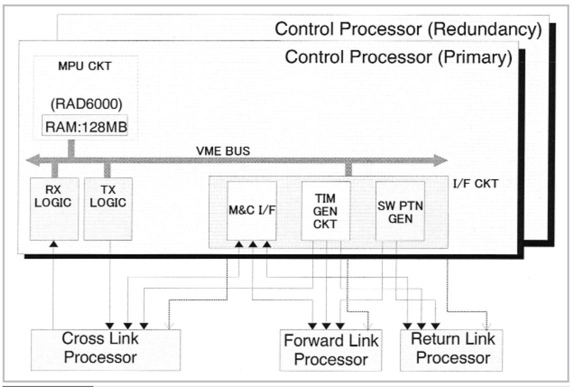

Fig.6 *Block diagram of the control processor*

tor and Viterbi decoder circuits. Fig.5 shows a function block diagram of the demodulator.

The demodulation and modulation unit feature no redundancy, although they employ two different modem patterns—one for control signals and other for communication signals. Switching between these two patterns is performed via commands. There are two interface circuits; whichever one is connected to the activated control processor is used. The power supply conducts primary power conversion from DC 100-V bus power to DC 24 V. The voltage required for each circuit is generated by a secondary power supply installed in each substrate. This circuit has a main unit and a redundant unit, and one or the other is selected by a command executed upon OBP activation.

7 Control processor

The control processor software runs the OBP self-contained switching function; control processors A and B work to monitor and control the OBP as a main one and a redundant one performing the same functions.

Fig.6 shows a block diagram of the control processors. This device uses a 20- MHz RAD-6000, equivalent to the IBM Power CPU. Memory capacity is 128 MB, approximately 1 MB of which is used by the software. The onboard software stored in the ROM checks the operation of each processor upon activation and turns on the channel pre-assign communications function.

All clock signals for the OBP are supplied by the control processor, and the interfaces of the other processors operate relying on the clock signals supplied by the interface of the activated control processor. The power supply conducts primary power conversion from DC 100-V bus power to DC 24 V. The voltage required for each circuit is generated by a secondary power supply installed in each substrate.

Bus commands (other than those to power on and off the OBP) are received by the control processor and used to control individual processors as required.

8 Communications method

This system adopts the MC-TDMA method using $\pi/4$-shift QPSK modulation. Fig.7 shows the relevant frame structure. A multi-frame structure is employed in the present system, and the communication process is controlled for each major frame. Only the top of the major frame uses a long preamble in voice communications. The remaining frames use a short preamble, in order to increase the data rate. Channel efficiency is increased through appropriate allocation of the reference signals and the communications control channels. A “super frame” is deemed to exist on the major frame. This frame functions, for example, when the channel capacity for each beam has changed. This frame is provided with no other special functions.

Cross link communication involves regenerative repeating, which results in one-slot delay. As a result, during the output of regenerative signals in voice communication, the top of the major frame features a short preamble and the second frame has long preambles.

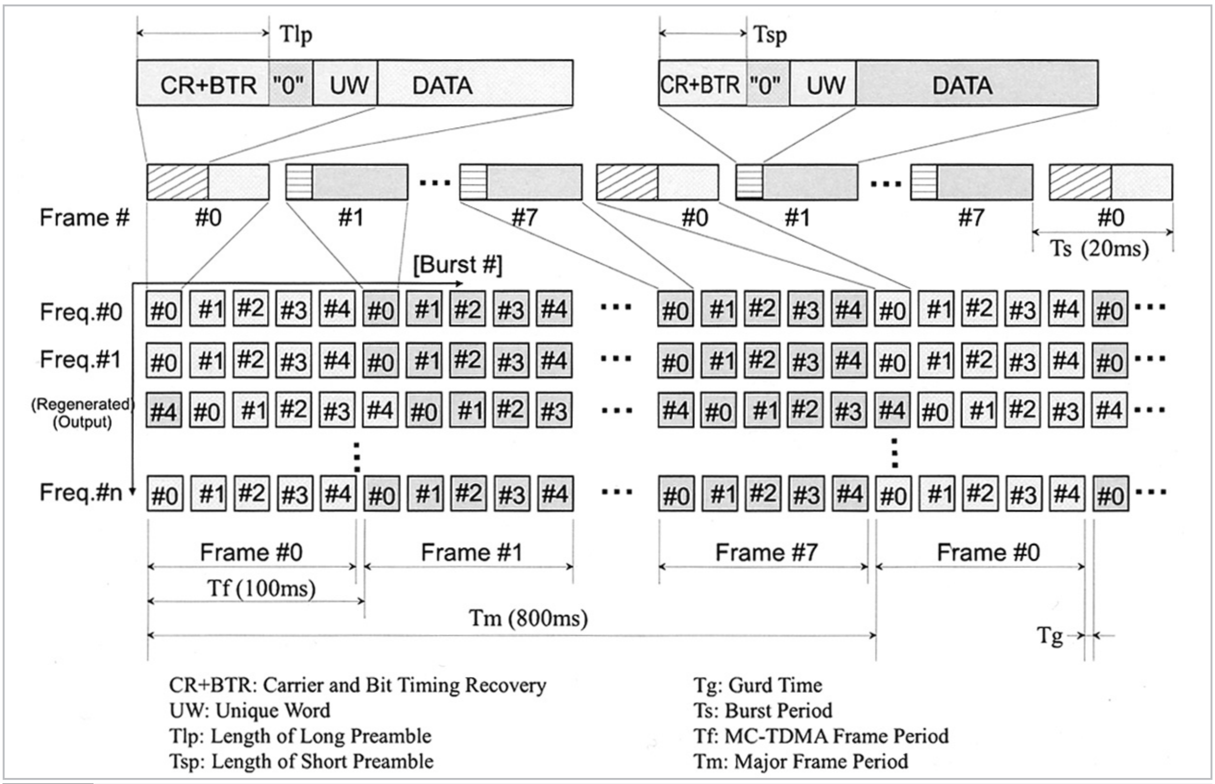

Fig.7 *Frame structure in MC-TDMA*

Voice data occupies 5 slots. Because of the one-slot delay, the second and latter frames are sent out.

9 Software

The system uses VxWORKS as the Operating System. The size of the software (including this OS) is 261 KB.

Fig.8 shows the OBP mode transfer diagram. The software eventually establishes two modes—wait mode and normal operation mode—as follows. After powering on from the off mode, the installed software conducts a self check and enters wait mode automatically from standby mode. After the control signal switches the OBP from wait mode to download mode, software for normal operation mode is downloaded to the OBP through the communication link. After downloading, the control signal switches OBP control to the normal operation software, thus activating the normal operation mode. Additionally, a reconfiguration mode is used to set OBP parameters and to modify status during normal operation. No communication is possible in this mode.

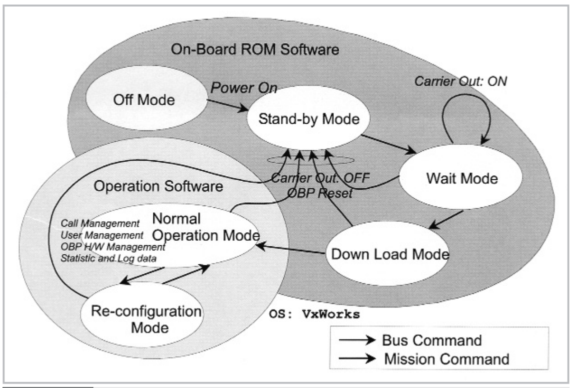

Fig.8 *OBP operation mode transfer diagram*

The main function of the wait mode is to check the status of the OBP and to implement communication by channel pre-assignment. In conjunction with timing-control bursts (which are used to measure TDMA timing between transmit signal and reference signal), the software activates a function indicating the delay clock number. The frequency as well as the transmission timing of handheld terminals must be fine-tuned based on the response to these timing-control bursts. The software indicates a coarse value, but values for each beams must be set after the OBP has been activated.

The normal operation software runs in the normal operation mode. Fig.9 shows the functions of this software. The call management function carries out call control, mobility management, and radio transmission management. The user management function executes the management of phone numbers. The hardware management function monitors and controls the OBP itself. The statistics and log data management function records the OBP status and communication records and provides this data to ground stations.

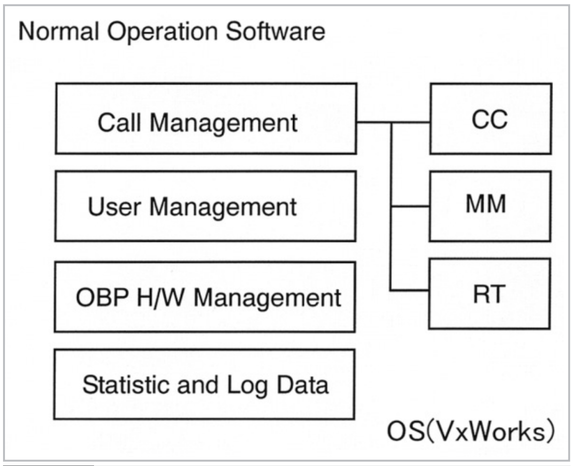

Fig.9 Functions of the normal operation software

The control data is exchanged between the OBP and handheld terminals via two layers—a physical layer corresponding to the actual wireless communication and a logical layer corresponding to the modeled control process. This design enables the system to adapt to changes in the physical layer. Fig.10 shows an example of a connection sequence. The handheld terminal must be registered in the OBP prior to its use. The terminal makes a connection request for a call, and control (such as paging channel assignment) is carried out. Burst timing correction is made before the connection control sequences, and physical layer control is performed (e.g., a request for control channel assignment for communication in the logical layer). Although the modeling of the control process provides flexible control independent of the real channel structure, traffic is increased because of the extra communication required for control; as a result the configuration is somewhat redundant as applied to satellite communication.

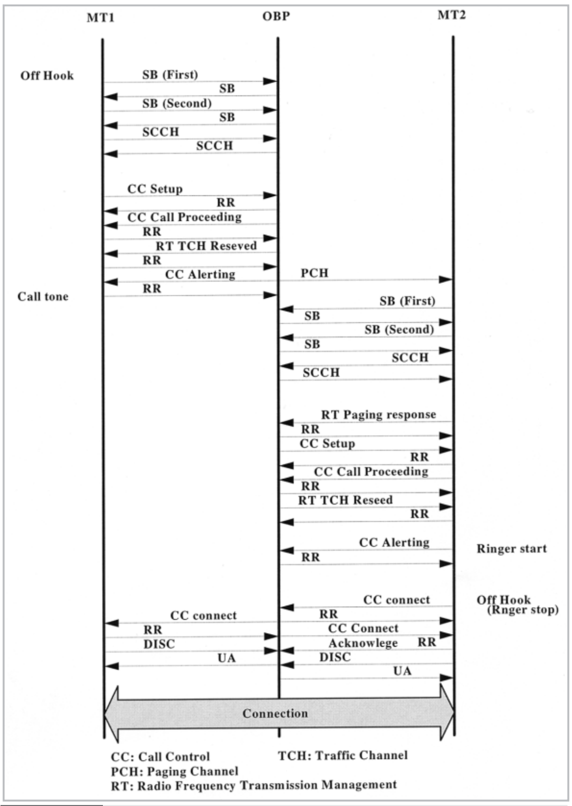

Fig.10 Call control sequence

The OBP is designed to conduct many of the traffic controls by itself, so that the overall system will continue to work only by allocating a channel capacity for each beam through the control station.

10 Performance check test

After each device was subject to electrical, environmental, mechanical testing, OBP combined with S-band transponder was checked [4][5]. And an overall communication performance check for communication equipments installed in the ETS-VIII was performed by NASDA (National Space Development Agency of Japan, now JAXA: Japan Aerospace Exploration Agency) [6]. Fig.11 shows a picture of the OBP installed in the satellite.

Filtering is performed during signal exchange between the ground base station and handheld terminals for carrier separation, exchange, and combination. Fig.12 shows the OBP filtering performance in the non-regenerative repeating channel. Because of the priority placed on filtering performance, the filter's bandwidth is narrower than the modulation spectrum and the roll-off shaping effect is weakened in the modulator/demodulator.

Regenerative repeating is performed in communication between mobile terminals. The system is equipped with a modulator/demodulator to transcribe switching control signals. Fig.13 shows the spectrum of an S-band SSPA output of regenerated signals.

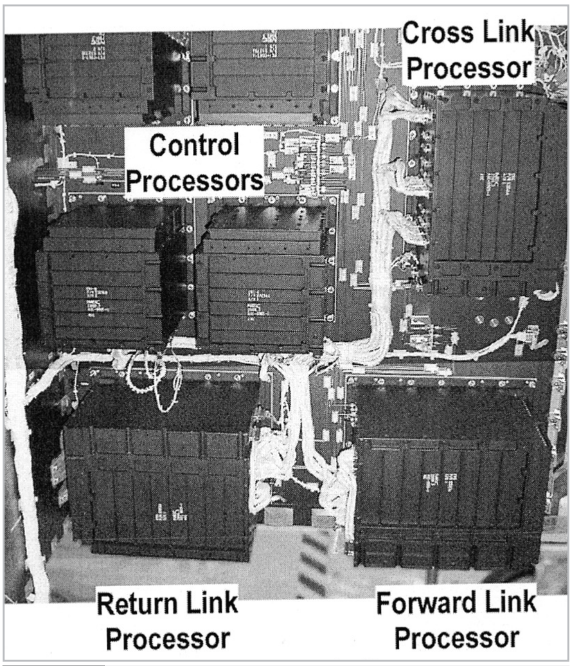

Fig.11 Picture of the OBP

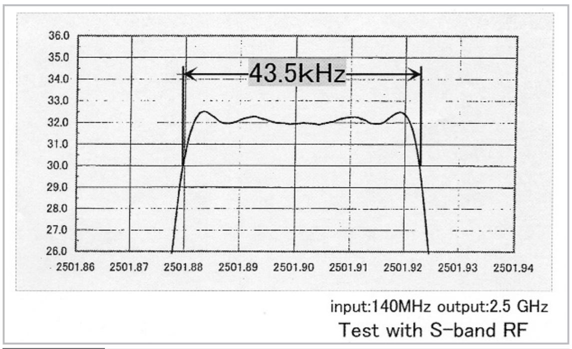

Fig.12 Filtering performance in non-regenerative repeating channels

Although the spectrum presents line-like spurious noise due to quantization and calculation errors, this noise level is lower than the noise level of reception during non-regenerative repeating. In addition, some leakage of local signals and signal ghosts are produced by mismatching in the quadrature modulator. This problem could probably be solved by adopting a digital circuit in the hardware configuration (including the quadrature modulator).

Fig.14 shows the bit error rate in the overall communication performance test. Signals do not degrade during non-regenerative repeating, whereas a signal degradation of about 4 dB is seen during regenerative repeating, relative to the non-regenerative period. The OBP digitizes numerous processes. Since

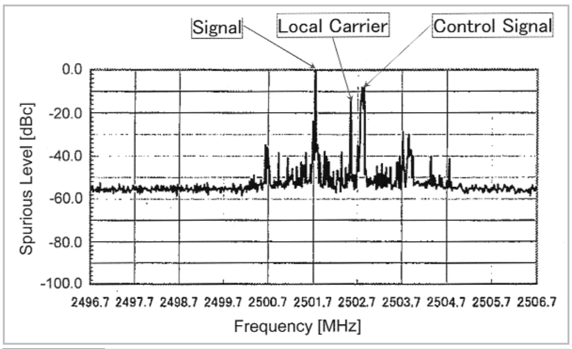

Fig.13 S-band spectrum of regenerated signals

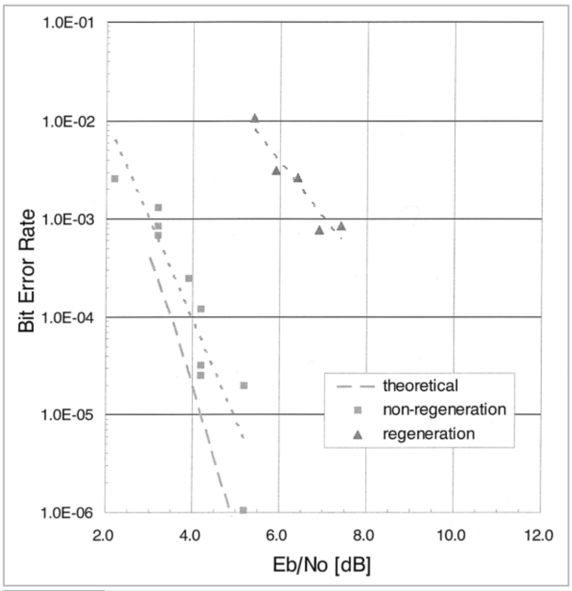

Fig.14 Bit error rate

it performs conversion of the 4-MHz analog signals to base-band signals and executes quadrature modulation, significant signal degradation is seen. Such digital processes may be optimized, for example in terms of calculation bit length.

Overall communications performance testing has indicated that handheld terminals can communicate with each other in the test mode, that the normal operation software can be downloaded successfully, and that the self-controlled switching function works normally in the normal operation mode.

11 Conclusions

We have developed an OBP serving as a satellite-borne, self-controlled switch for mobile voice communications. We installed the OBP in the ETS-VIII and examined the performance of the entire communications system. With the exception of an increase in the bit error rate, performance was as expected.

Many ASICs and FPGAs are used in the hardware of the OBP. Because such semiconductor devices designed for use in space must be durable enough to resist radiation and other harsh conditions, it is particularly troublesome that these devices are two to three generations behind those designed for ground use. It is anticipated that continued rapid progress in semiconductor technology will produce FPGAs that can be re-programmed to act as modulators/demodulators or as demultiplexer/multiplexer circuits. It will also become possible to correct an increased error rate in the OBP even after launch.

This OBP was developed by the Advanced Space Communications Research Laboratory (ASC), and taken over by the CRL after the former body completed its mission. If the ground base stations are well prepared, this OBP system will even be capable of connection to public telephone networks. For the time being, three prototype handheld terminals will be manufactured. One such terminal, with no RF unit, will be used as a control station for software loading and monitoring of OBP status. Another will be used as a terminal in the ground base station.

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