3-2 Communications System

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WINDS (Wideband InterNetworking engineering test and Demonstration Satellite) is an experimental satellite enables communications at significantly higher data rates. The satellite employs advanced technologies such as high G/T multi-beam antennas, high power multi-port amplifier, active phased array antenna and regenerative baseband switching, to realize both very high data rate transmissions and advanced broadband satellite networking. The satellite communication system aims at maximum rate of 155 Mbps (receiving)/6 Mbps (transmitting) for home use using a 45-centimeter aperture antenna and ultra high speed of 1.2 Gbps (receiving/transmitting) for office use using a 5 meter class aperture antenna. In this paper, communications system and function and performance of transponders of the WINDS are introduced.

Keywords
WINDS, Ka band, Fixed satellite communications, MBA, APAA, MPA, Regenerative repeater

1 Introduction

The Wideband InterNetworking Engineering Test and Demonstration Satellite (WINDS) is an experimental satellite system aimed at the establishment of a high-speed Ka-band satellite communications system. Its purpose is to demonstrate the technologies required to construct a satellite communications network that can complement ground communications networks and vice versa. Specifically, the experimental system will demonstrate (1) high-speed transmission technology required for data transmission at a rate of 155 Mbps for home use using a small earth station that can be installed on the balcony of an ordinary house, as well as data communication at a rate of 1.2 Gbps for use by common carriers; and (2) the wide-coverage technology required to implement high-speed satellite communications within Japan and the Asia/Pacific region, with a general view to greater international cooperation.

This paper describes the implementation of a satellite communications system that combines various technologies: a regenerative repeater, an inter-beam switching function, a high-power transmitter, and an active phased array antenna (APAA) that can electronically steer the beams. This paper also describes the configuration of the onboard transponder, provides an overview of its function, and its major specifications.

2 Overview of communications missions

Figure 1 shows a basic block diagram of the onboard transponder. This figure does not include details such as low-noise amplifiers and frequency converters. To enable establishment of a communication link between the satellite and a small earth terminal with restricted transmitting and receiving capabilities, the transmitting and receiving capabilities of the satellite need to be correspondingly improved. WINDS is equipped with a set of large-aperture multi-beam antennas (MBA) and a high-power amplifier. The specific high-power amplifier adopted is a 300 W multiport amplifier (MPA) with eight input ports and eight output ports. An MPA is a type of power-combined amplifier that combines eight sets of traveling wave tube amplifiers (TWTA) with a linear output power of approximately 50 W. By setting the signal power of each input port, one can arbitrarily control the output signal power for each output port, at values of up to 300 W. Taking advantage of this characteristic, the MPA can flexibly assign high power to the beam for a rainy area, where the signal transmitted from the satellite is attenuated, with less power allocated to the beam for clear areas. In this manner, the MPA makes the most effective use of transmitting power, a valuable asset for any communications satellite. The operating point of TWTA is set within a linear region, in a configuration premised upon multi-carrier amplification.

To provide opportunities for satellite communications experiments not only within Japan but also in the Asia/Pacific region, WINDS provides fixed beams with high antenna gain to ten major cities in Asia and supports communications in other areas (e.g., regions targeted for

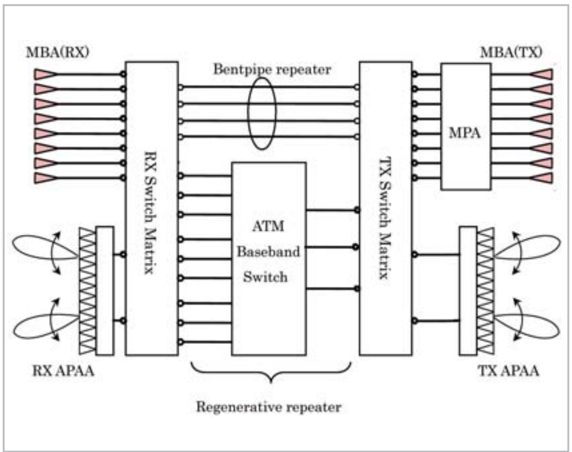


Fig.1 Block diagram of the transponder

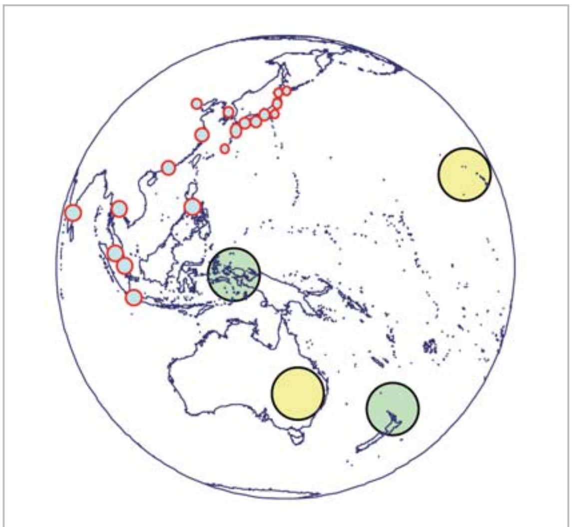


Fig.2 Beam direction (MBA beams denoted by small circles, APAA beams denoted by large one)

Table 1 Major specification of communications mission

	MBA/MPA	APAA
Frequency band	TX : 17.7〜18.8 GHz RX : 27.5〜28.6 GHz	
Antenna type	Aperture dia.:2.4m Offset Cassegrain	Direct radiating phased array antenna
Number of beams	Japan & neighboring countries:12 South-east Asia:7	TX:2 RX:2
G/T	approx.18 dB/K (at beam edge)	approx. +7.5 dB/K (θ =±8 deg.)
EIRP	approx.70dBW (at beam edge and maximum MPA output)	approx. 55 dBW (θ =±8 deg.)

Table 2 Antenna diameter of earth stations vs. data rate

	Antenna dia.	Repeater mode	Data rate (Mbps)
Large Earth Terminal	5 m class	Bentpipe	U/L : 622、1244 (622×2carr.) D/L : 622、1244 (622×2carr.)
SDR-VSAT	2.4m class	Bentpipe	U/L : 622 D/L : 622
HDR-VSAT	1.2m class	Regenerative	U/L : 1.5、6、24、51、155 (51×3carr.) D/L : 155
USAT	45cm class	Regenerative	U/L : 1.5、6 D/L : 155

SDR-:Super High Data rate, HDR-:High Data rate, VSAT: Very Small Aperture Terminal, USAT: Ultra Small Aperture Terminal, U/L: Up Link, D/L: Down Link

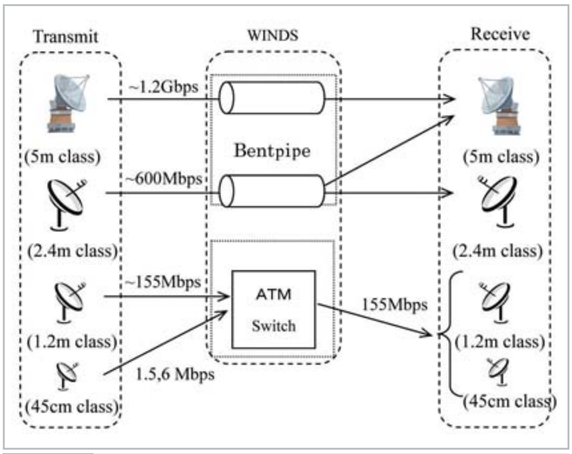


Fig.3 Communication links among earth terminals

new communication experiments or points scattered throughout a wide area, such as islands) using an active phased array antenna (APAA), which can electronically steer the beams (i.e., perform beam hopping) instantly and arbitrarily. Figure 2 shows the distribution of the antenna beams.

The ATM-based baseband switching subsystem (ABS) consists of modulators, switches, and demodulators, and forms the core component of the regenerative repeater function.

Table 1 shows the major specifications of the communications missions, and Table 2 shows the classification of user earth terminals, the communications capability, and the repeater mode. Figure 3 shows an example of satellite communication links.

3 Repeater modes and inter-beam switching

3.1 Repeater modes

WINDS supports the use of the regenerative and bent pipe modes as repeater modes. Both repeater modes are based on SS-TDMA (Satellite Switched Time Division Multiple Access). In bent pipe mode, the uplink signal received by the satellite is frequency-converted and power-amplified and is then transmitted as the downlink signal. The frequency bandwidth is 1.1 GHz, and the repeater can transmit communication signals at a maximum 1.2 Gbps.

In regenerative-repeater mode, the uplink signal is first demodulated to the baseband signal in the satellite and then modulated again and transmitted as the downlink signal. Thus, the repeater can also provide various additional functions that are impossible in bent pipe repeater mode, including a switching function and digital processing within the satellite.

The WINDS regenerative repeater mode uses a type of fixed length packet known as the ATM (asynchronous transfer mode) cell as the minimum unit of communication. The switch looks up the ATM header, which corresponds to the address information of the destination earth terminal, from the ATM cell and identifies the downlink beam to be output based on the header information. Thus, the data from one earth terminal to two or more earth terminals can be switched to suitable beams within the satellite if the data are transmitted to the satellite as batch data.

The demodulator of the ABS is a multi-rate demodulator and supports four uplink transmission rates: 1.5 Mbps, 6 Mbps, 24 Mbps, and 51 Mbps. Given that the cost of the transmitter cannot be ignored when considering the overall costs of an earth terminal, this system allows the user to select a transmission rate according to a budget, which widens the range of selection of satellite communication services for the user. Users who require a higher transmission rate can choose the 155 Mbps transmission rate, which consists of three 51 Mbps channels. The transmission rate of the demodulator is selectively switched at a minimum time interval of 2 ms in synchronization with the receiving timing of the uplink signal.

3.2 Inter-beam switching

A multi-beam system equipped with many beams requires a function to connect two or more receiving and transmitting beams so that communication links can be established between arbitrary locations. WINDS is equipped with switch matrices consisting of many 4 GHz band analog switches; the system switches patterns of combinations of the receiving and transmitting beams over time (at a minimum time interval of 2 ms). The receiving switch matrix selects the uplink beam, while the transmitting matrix selects the downlink beam. If the switching pattern of the switch matrices is set to fixed, continuous wave communication is also possible. The switching patterns (including beam directions for the APAA) are uploaded from the network management center (NMC). With this inter-beam switching function, WINDS can construct a mesh network that can connect numerous earth terminals directly at high data rates.

In principle, the regenerative repeater mode features the inter-beam connection function. If a satellite is equipped with the same number of modulators and demodulators as the number of antenna beams, there is no need for switch matrices in inter-beam connection. However, WINDS has only three sets of demodulators and modulators — fewer than the number of antenna beams. WINDS combines the switch matrices, demodulators and modulators jointly to secure the number of required combinations of inter-beam connections.

In this manner, the switch matrices also enable connection between the MBA and the APAA in addition to inter-beam connection within the MBA or within the APAA. Here, due to the restriction on the number of MPA output ports, the MBA can select and use up to eight transmitting beams at the same time of the 19 beams of the MBA.

4 Frequency allocation

Figure 4 shows the frequency allocation planned for the WINDS system. Acknowledging the need to protect operations of earth exploration satellites ("passive" satellites), the plan allocates 27.5 – 28.6 GHz for uplink communication and 17.7 – 18.8 GHz for downlink communication. A frequency bandwidth of 1.1 GHz can carry a 1.2 Gbps transmission signal. The bandwidth of the regenerative repeater mode consists of the lower half (550 MHz) of the entire 1.1 GHz bandwidth. This 550 MHz bandwidth contains three 155 Mbps downlink channels and nine uplink channels that can provide rates of 6 Mbps, 24 Mbps, or 51 Mbps. Each of the uplink channels can also be used as 14 channels of 1.5 Mbps links.

In bent pipe mode, two signal channels equivalent to 622 Mbps QPSK are placed within the 1.1 GHz bandwidth. In the mixed repeater mode of the regenerative repeater and bent pipe repeater, one 622 Mbps QPSK signal is placed in the upper part of the 1.1 GHz bandwidth, the nine possible uplink channels are limited to six, and the three downlink channels are limited to two for the regenerative repeater.

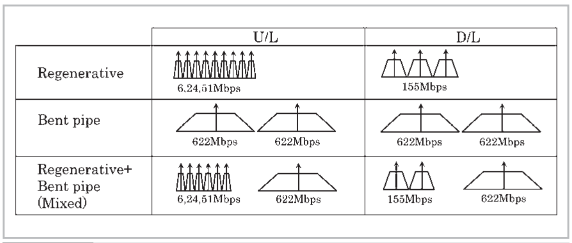


Fig.4 *Frequency allocation*

5 Details of transponder

5.1 Overview of operation

Figure 5 shows the configuration of the transponder in detail. The 28 GHz uplink sig-

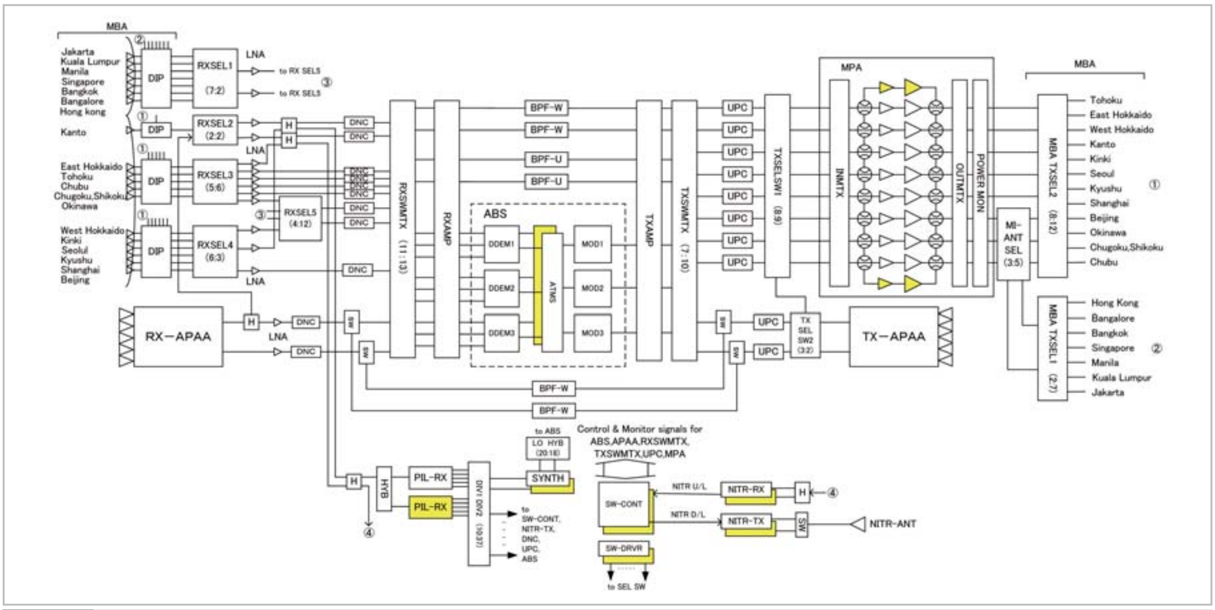


Fig.5 *Detailed block diagram of the tranponder*

nal received by the MBA or the APAA is first low-noise amplified, and then converted to a 4 GHz band intermediate frequency signal by the down-converter, or DNC (local frequency: 24.12 GHz), and input into the receiving switch matrix, RXSWMTX. The RXSWMTX consists of a large number of fast-switching switches. The input and output ports are connected and switched in accordance with switching control by the switch controller, SW-CONT. Each connection of the input and output ports in principle involves one input and one output. However, a signal-dividing connection with one input and N outputs (one to N connection) is also possible. For example, through a one to two connection, both regenerative and bent pipe repeater signals simultaneously uplinked from the same beam are distributed to the ABS and the bent pipe repeater.

The bent pipe repeater route contains two types of bandpass filter: BPF-W and BPF-U. The BPF-W allows pass-through of a bandwidth of approximately 1.1 GHz and BPF-U passes through approximately 600 MHz of the upper part of the 1.1-GHz bandwidth. The BPF-U is used in the mixed modes and suppresses the regenerative uplink signal component as unnecessary in the downlink connection.

The transmitting switch matrix, TXSWMTX, has a function similar to the RXSWMTX except that the bent pipe signals from BPF-W can be connected only to specific output ports, while other signal inputs can be connected to any output port. Here, unlike with the RXSWMTX, signal-combining connection with N inputs to one output (N to one connection) is also possible. This function combines the bent pipe signal and the ABS MOD output signal in the mixed repeater mode. As for the receiving RX-APAA and transmitting TX-APAA, RX-APAA Beams 1 and 2 can be directly connected even to TX-APAA Beams 1 and 2 without passing through RXSWMTX or the TXSWMTX (APAA direct connection mode).

The 4 GHz intermediate frequency signal goes through an up-converter, or UPC (local frequency: 14.32 GHz), is converted to an 18 GHz band signal, and input to the MPA and the TX-APAA. The output power of the MPA and the TX-APAA are controlled through gain control of the transmitting amplifier, TXAMP, or the UPC.

5.2 Frequency control and TDMA time reference

The pilot signal receiver, PILRX, receives a Doppler effect-compensated 28.8 GHz pilot signal (unmodulated continuous wave) transmitted from the NMC, generates a 20 MHz signal coherent with the pilot signal as a reference signal, and supplies the signal to the DNC, the UPC, the network management information transmitter (NITR-TX), the synthesizer (SYNTH), the SW-CONT, and the ABS. Here, the DNC, the UPC, and the NITR-TX generate the 24 GHz, or 14 GHz band local frequency from the 20 MHz signal. The SYNTH receives the 20 MHz signal and supplies ten kinds of local signals for the ABS: nine signals at different frequencies of 2637.0 MHz, 2692.5 MHz, 2748.0 MHz, 2822.0 MHz, 2877.5 MHz, 2933.0 MHz, 3007.0 MHz, 3062.5 MHz, and 3118.0 MHz, and an additional 780 MHz signal.

The timing signals required to control the TDMA (slot timing, frame timing, and super frame timing) are generated from the 20 MHz reference signal described above and distributed to each device from the SW-CONT. Thus, the TDMA of WINDS uses a satellite-based time reference. As a result, the entire communication system can provide a stable timing system based on the pilot signal from NMC as the master clock signal. For the user earth terminal in the communication experiments, this timing system reduces the carrier acquisition range of the demodulator and simplifies the estimation of uplink transmitting timing.

5.3 Slot control information

The TDMA slot control table placed in the SW-CONT sets various parameters for each TDMA slot in a super frame (20 slots × 16 frames): the switch patterns for the

RXSWMTX and the TXSWMTX, the TXAMP gain, the UPC gain (10 sets), the ABS DDEM demodulation rate, the APAA beam directions (two beams each for transmission and reception), and the control information (attenuator value and phase value) for the driver amplifier of the MPA (10 sets). These items of control information are input to the SW-CONT through the 28.9 GHz network management information link (NMIL), and the SW-CONT controls each device at the slot timing.

Considering that the contents of slot-control information is often the same for two or more slots, for the update of the slot-control information, we use a method that specifies the slot control information and the slot numbers (for arbitrary number of slots) that refer to this information. With downlink rain-attenuation compensation control, which requires a quick response, this method significantly reduces the delay in control.

5.4 Network management information links

Control information and monitoring information for mission devices (excluding housekeeping information) are transferred among the NMC and the network information transmitter and receiver, or NITR. These items of information include control and monitoring data for the APAA and ABS.

The uplink of the NMIL signal from the NMC is received via the MBA for Japan. If this MBA were to fail, we would not be able to control the mission devices and might not be able to perform most of the communication experiments. To avoid this risk, we have provided a backup receiving route for the NMIL signal and the pilot signal, through the RX-APAA. Specifically, the output signal of the RX-APAA beam 1 is divided and output to the receiving port of the MBA Kanto beam, where the NMC is located. Here, various control parameters for the APAA itself are also set through the NMIL. Thus, with the initial setting that directs the receiving beam 1 toward the NMC, the SW-CONT is reprogrammed and set with the control parameter required for the initial setting of the APAA through the TTC link. Once the RX-APAA beam is set toward the NMC, the mission devices are controlled through the NMIL under normal operational procedures.

The transmitting antenna of the NMIL is a conical horn antenna with wide radiation pattern. A large earth terminal can utilize the residual carrier of the phase-modulated signal of the NMIL for automatic antenna tracking and for transmit power control in conditions of rain.

6 Major characteristics

6.1 Transmission characteristics

Table 3 shows the major characteristics (mainly transmission characteristics) of the IF switch subsystem (excluding the MBA, MPA, and APAA). Table 4 shows the major characteristics of the NITR subsystem.

6.2 Signal level diagram

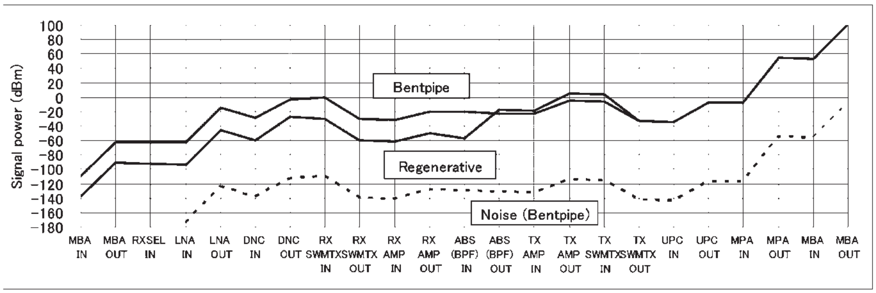
Figure 6 shows an example of the signal level diagram for a representative transponder setting. The noise level in the figure is the noise power density per 1 Hz output at that point.

Table 3 *Transmission characteristics of the IF switch subsystem*

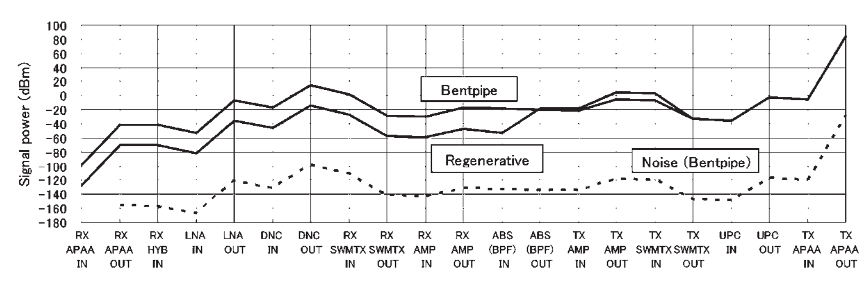
	Regenerative		Bentpipe
	LNA~ABS	ABS~UPC	LNA~UPC
Phase nonlinearity	≤ 5.7deg.0-P (±37MHz)	≤ 14.1deg.0-P (±90MHz)	≤ 20deg.0-P
Gain flatness	≤ 0.5dB0-P (±37MHz)	≤ 0.9dB0-P (±90MHz)	≤ 1.7dB0-P
Spurious PM	≤ 0.5deg.rms (±37MHz)	≤ 0.5deg.rms (±90MHz)	≤ 0.5deg.rms (±300MHz)
Residual AM	≤ 1.0% (±37MHz)	≤ 1.0% (±90MHz)	≤ 1% (±300MHz)
Spurious	≤ −35dBc (±37MHz)	≤ −35dBc (±90MHz)	≤ −35dBc (±300MHz)
Phase Noise	≤ 5deg.rms (1kHz~37MHz)	≤ 5deg.rms (1kHz~90MHz)	≤ 5deg.rms (1kHz~275MHz)

Table 4 *Characteristics of the NITR*

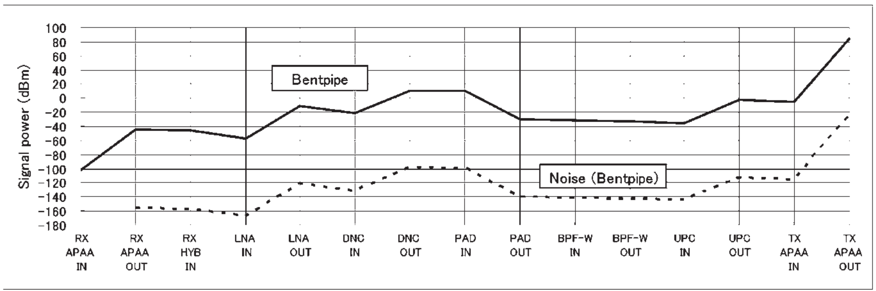
	U/L	D/L
Frequency	28.9GHz	18.9GHz
EIRP	−	≥ 15.7dBW (θ =8 deg.) ≥ 17.2dBW (θ =6 deg.)
Modulation	PCM(NRZ-L)/PSK/PM	
Sub-carrier	16 k Hz	40 k Hz
Modulation index	≤ 1.1rad±10%	
Data rate	4kbps	10kbps



(a) MBA-MBA route



(b) APAA-APAA route



(c) APAA-APAA direct route

Fig.6 *Signal level diagram of the transponder*

7 Conclusions

This paper presents an overview of the WINDS communications system and the onboard transponder function. Aiming at the launch of the satellite in fiscal 2007, we are now (as of September 2007) conducting a system test of the flight model. Also, for the overall set of communications missions, we are conducting end-to-end (user earth terminal - satellite-user earth terminal) testing using the system electric model (SEM) and are checking the networking protocols. The WINDS communications missions are uniquely designed, and we have high expectations that the functions provided will contribute to cultivating various kinds of new applications in satellite communication technologies.

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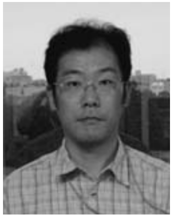
Satellite Communications



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