3-6 Ka-band Active Phased Array Antenna

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Active Phased Array Antenna (APAA) is one of mission equipment on WINDS and the frequency band is Ka band, and maximum data rate 1.2 Gbps communication will be realized by APAA. It consists of 128 element antennas and many extremely miniaturized RF modules. It can scan two beams of a transmitting antenna and a receiving antenna electronically and independently. WINDS service area covers almost all of the world which is a visible region from the satellite by APAA.

This paper introduces APAA role, background, functions, key technologies, and major specifications, and describes development results.

Keywords
Active phased array antenna, Beam steering controller

1 Introduction

The Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) is equipped with a Ka-band Active Phased Array Antenna (APAA) among the mission equipment. This APAA consists of a transmitting antenna and a receiving antenna, each of which consists of 128 element antennas and high-density RF modules attached to the element antennas. With these components, the transmitting and receiving antennas can each electronically scan two independent beams. Consequently, the WINDS service area covers almost the entire visible region of earth from the satellite.

This article describes the operations and roles of the APAA in Section **2**, major functions and key technologies in Section **3**, major specifications in Section **4**, technical development in Sections **5**, and the development results in Section **6**.

2 Operations and roles of the APAA

We are developing the APAA as a beam-hopping antenna within a satellite system. To implement ultra-high-speed global communications within and outside of Japan, we must provide communication characteristics with high equivalent isotropic radiated power (EIRP) and high gain/temperature ratio (G/T) in terms of antenna performance. In addition, to provide fast communications to an arbitrary location via communication demand, it must be possible to control the antenna beam direction electronically at high speed. Various APAA techniques described in the following and subsequent sections are used to implement these requirements. We have planned operations of large-capacity high-speed transmission up to 1.2 Gbps, high-speed transmission at 622 Mbps in non-regenerative mode, and transmission at 155 Mbps in regenerative mode. Diverse forms of operations are possible according to the scale of the earth stations. As shown in Fig. 1, the beam scan range of the APAA is set to cover almost the entire visible region from WINDS. The most prominent feature of the APAA is its provision of communications between arbitrary locations. Taking advantage of this feature, communication lines can be ensured regardless of destination, particularly in disasters. Accordingly, expectations are high for the APAA within both domestic and international circles.

3 Major functions and key technologies of the APAA

3.1 Major functions

The major functions of the APAA are as follows.

(1) Antenna reception function for receiving and amplifying 28-GHz-band uplink signals and antenna transmission function for amplifying and transmitting 18-GHz-band downlink signals

(2) Beam-steering function with two independently steerable beams for each of the transmitting and receiving antennas

(3) Beam-steering function supporting operations in continuous wave mode and in SS-TDMA (Satellite Switched-TDMA) mode

(4) Supplementary functions for facilitating fault diagnosis for APAA elements in orbit

3.2 Key technologies

The key technologies of the APAA are as follows.

(1) Development and high-density packaging of high-frequency devices (including high-power amplifiers, low-noise amplifiers, and phase shifters) using microwave monolithic integrated circuit (MMIC) technology, which can reduce size, weight, and power consumption of devices to allow installation aboard a satellite.

(2) To implement diverse types of communications, the APAA uses an antenna control method that allows for both continuous wave mode and SS-TDMA mode. For the SS-TDMA mode, we have developed a beam-steering controller that can rapidly steer two beams for each of the transmitting and receiving antennas at 2 ms intervals.

(3) To guarantee the stand-alone performance of the APAA, we have developed a self-thermal-control function and provided the APAA body structure with a three-dimensional waste-heat dissipation method based on connected heat pipes.

4 Major specifications of the APAA

Table 1 shows the major specifications of the APAA. Figure 2 is a block diagram. Figure 3

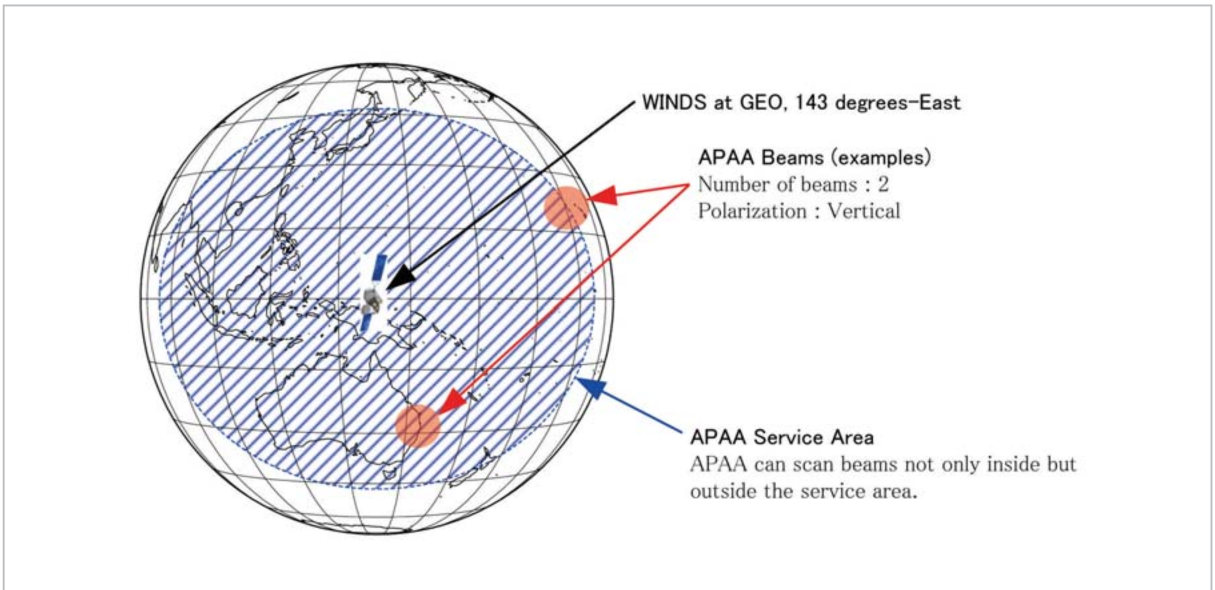

Fig. 1 Communications coverage of the APAA

Table 1 Major specifications of the APAA

Item	Unit	APAA	
		TX antenna	RX antenna
Antenna type	—	Direct radiating phased array antenna	
Dimensions	mm	1510×990×1530	
Mass	kg	183	
Aperture size	mm	649×539	287×468
Frequency band	GHz	18	28
Frequency bandwidth	GHz	1.1	
Numbers of Radiation Elements	—	128	128
Polarization	—	Linear	
FOV	deg	Azimuth : 8, Elevation : 7	
Number of beams	—	2	2
EIRP	dBW	≥ 54.6 / 1 beam ≥ 52.1 / 2 beams	—
G/T	dB/K	—	≥ 7.1
Phase shifter bit number	bit	5	5
Operating mode	—	SS-TDMA mode Continuous wave mode	
Beam hopping time	ms	2 (at SS-TDMA mode)	
Power consumption	W	≤ 750	

shows the APAA appearance, which mainly consists of a transmitting antenna, a receiving antenna, the beam-steering controller (BSC) to control the antennas, DC/DC converters (DC/DCs) to supply power to them, a heater control unit (HCU) to control the heaters, and power distribution units (PDUs) to distribute the bus voltage within the APAA. The heat pipes are placed on the three panels of the APAA body structure to provide for three-dimensional waste-heat dissipation.

Figure 3 also shows a definition of the relevant coordinate system. θ indicates the half-

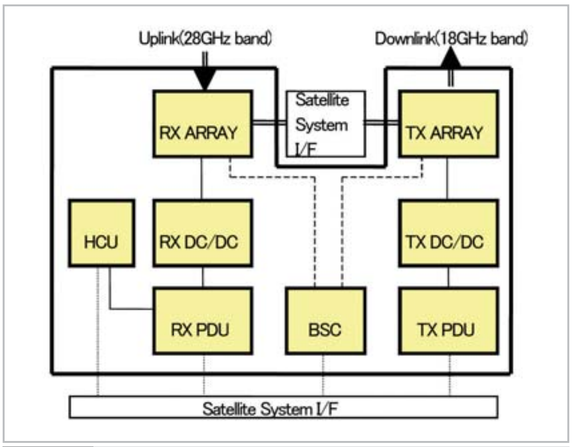

Fig.2 Block diagram of the APAA

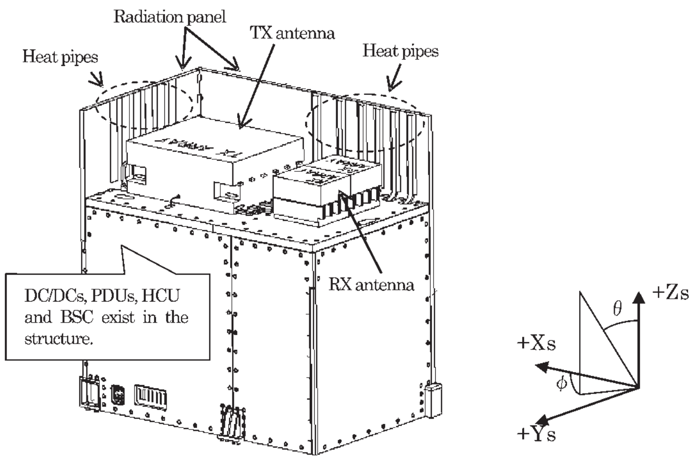

Fig.3 APAA appearance and coordinate system

cone angle to the APAA front face (direction of the sub-satellite point). The ϕ = 0° plane is the orbit plane (east-west direction) and the ϕ = 90° plane is the plane perpendicular to the orbit plane (north-south direction).

5 Technical development of the APAA

5.1 Design of transmitting and receiving antenna RF systems

Each of the transmitting and receiving antennas consists of 128 element antennas. The element antenna adopted is of a pyramidal horn structure. The element arrangement is designed with consideration given to the field of view of the earth from a geostationary orbit, such that the grating lobe is out of the field of view of the earth, regardless of the beam-scan direction. Figure 4 shows the appearance of the transmitting and receiving antennas.

To implement two beams, the transmitting and receiving antennas have two phase shifters per element antenna. Adopting high-density packaging using MMIC technology has reduced the size of the antenna. The high-power amplifiers and low-noise amplifiers are also reduced in size using MMIC technology, which has also reduced power consumption and the weight of the APAA. Figure 5 is a block diagram of the transmitting and receiving antennas.

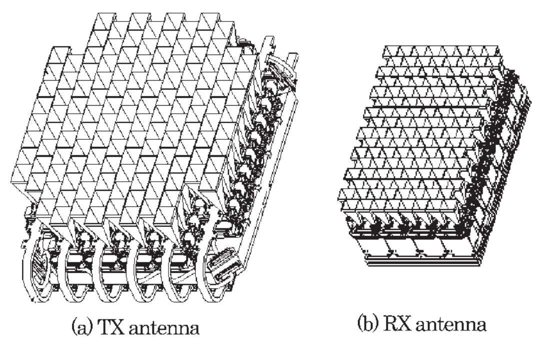

Fig.4 *Appearance of transmitting and receiving antennas*

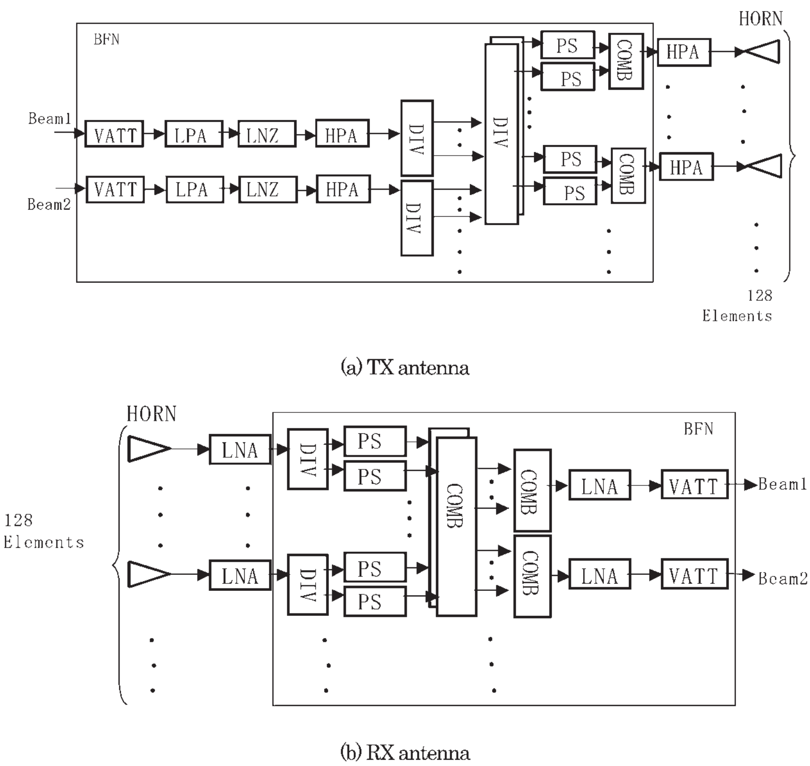

Fig.5 *Block diagram of transmitting and receiving antennas*

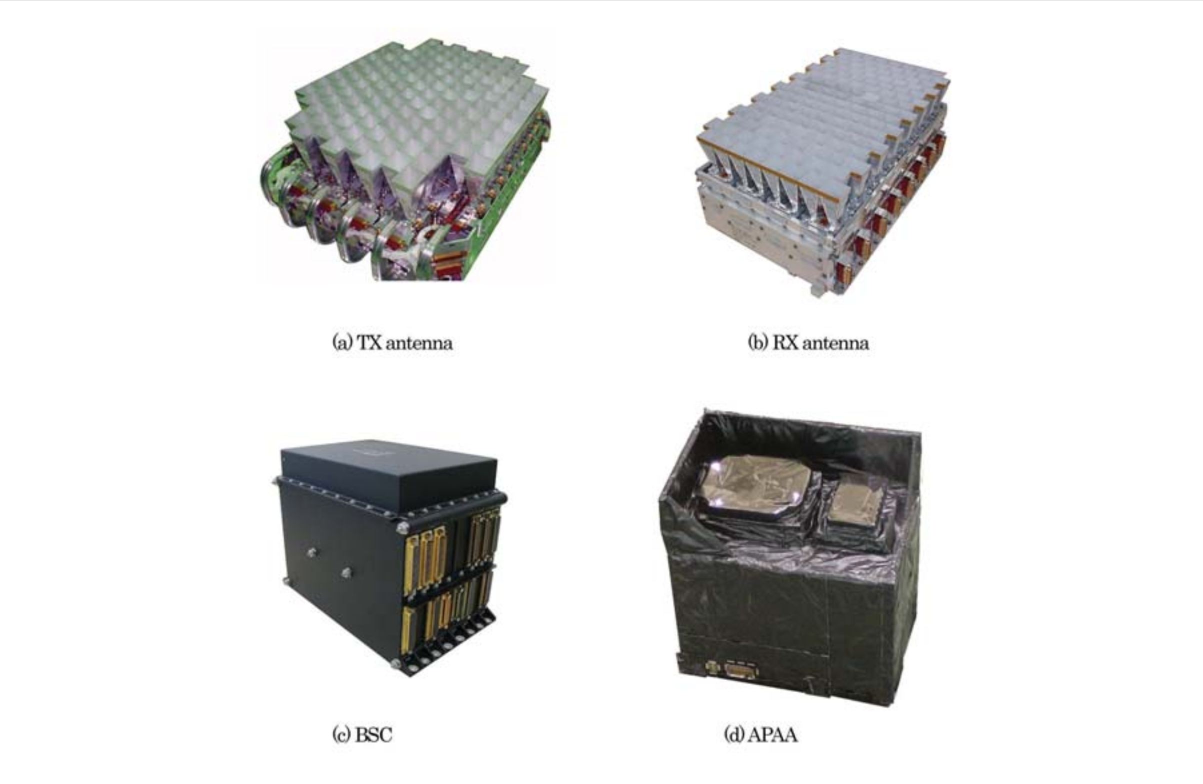

Fig.6 Photos of the PFMs of the transmitting antenna, receiving antenna, BSC, and the APAA

5.2 Design of beam-steering system

The beam from the APAA is controlled by the beam-steering controller (BSC). The BSC provides independent control of the 5-bit digital phase shifters, which support two beams for the transmitting and receiving antennas. The BSC also supports diverse communications in continuous wave mode and in SS-TDMA mode. Beams can be switched at high speed in SS-TDMA mode and can operate with up to eight beam point directions per beam. In addition, the BSC also controls variable attenuators in order to maintain internal gain according to temperature changes in orbit.

5.3 Design of thermal control system

The APAA's thermal design is independent of the satellite system. Temperature control in orbit consists of self-thermal-control combining heaters and active thermal control using heat pipes. There are two types of heaters for thermal control of APAA: replacement heaters supporting command-based ON/OFF control, and an automatically controllable thermal control heater. HCU controls these heaters to provide thermal control over APAA. Included among the heat pipes are three-dimensional heat pipes embedded in the APAA body structure and heat pipes embedded in the transmitting antenna.

6 Development results of the APAA

After we completed manufacturing and testing of the components of the APAA Proto Flight Model (PFM), we assembled and tested the APAA. The test results satisfy the required performance. Figure 6 shows photos of the PFMs of the transmitting antenna, receiving antenna, BSC, and the APAA.

Figure 7 shows the radiation characteristics of the APAA, and Fig. 8 shows its amplitude-frequency characteristics. The graph of the radiation characteristics is normalized with peak gain. Thus, the amplitude values look alike when the beam scans in the two directions of $\theta = 0^\circ$ and $\theta = 8^\circ$. However, considering the contribution (i.e., element factors) of

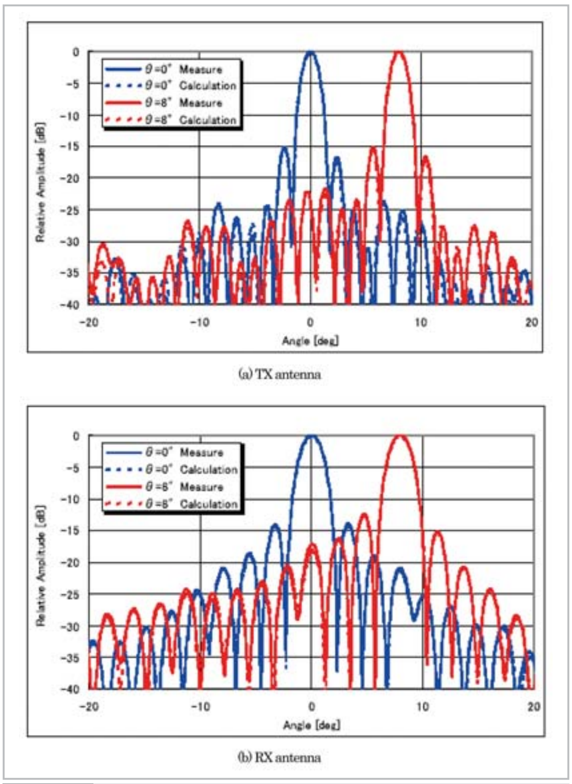

Fig.7 *Radiation characteristics of the APAA*

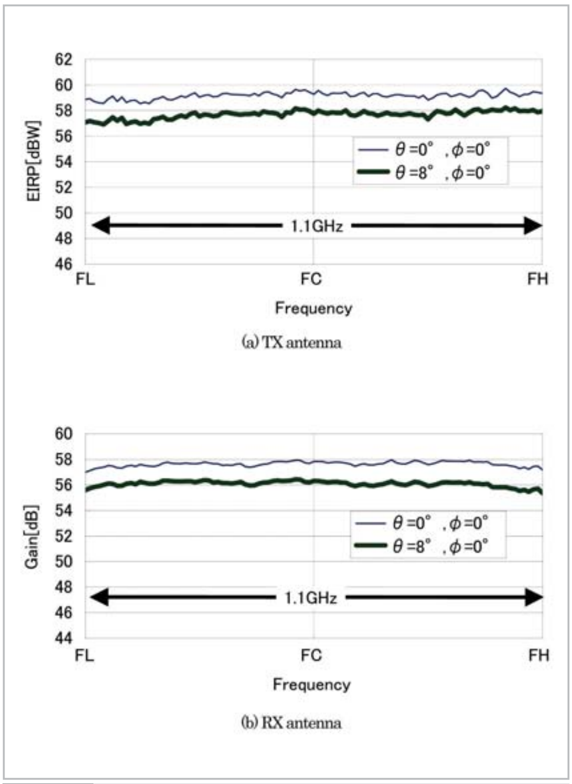

Fig.8 *Amplitude-frequency characteristics of the APAA*

the radiation pattern of the cone-horn antenna, which is the radiation element, the peak gain at $\theta = 0^\circ$ is larger. The gain in the vertical axis of the amplitude-frequency characteristics of the receiving antenna as shown in Fig. 8 represents the gain of the entire receiving antenna including the amplifiers and other devices except the element antennas.

7 Conclusions

This article describes the operations and roles of the Ka-band APAA installed on WINDS and indicates the functions and performance of the APAA and the technologies required to achieve them. It also shows the results of the development of Ka-band active devices with consideration given to mass and power consumption, as well as the design points and features of beam steering and thermal control. After manufacturing and testing the components of the APAA PFM, we assembled and tested the APAA. The test results satisfy the required performance.

In the future, the APAA will be installed on the satellite main body and the functions and performance of the entire communication mission system will be tested.

Acknowledgment

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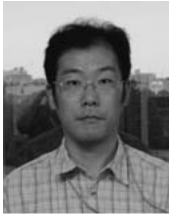

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