On-board evaluation results of Active Phased Array Antenna for WINDS satellite

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1. Introduction

Phased Array Antennas (PAAs) have attracted attention for use as a hopping spot beam antennas that might be used as an electronically controllable onboard satellite antenna. In fact, a Ka band APAA [1] is installed on the KIZUNA (Wideband Internetworking engineering test and Demonstration Satellite: WINDS) [2] developed by JAXA and the National Institute of Information and Communications Technology (NICT). Actually, WINDS was developed to construct a high-speed satellite communication system and demonstrate the advanced technology that is necessary for formation of a satellite communications network. It was launched by an H-IIA Launch Vehicle in February 2008.

The APAA comprises a transmitting (TX) array antenna and a receiving (RX) array antenna; each antenna has two hopping spot beams. Each beam's direction can be controlled independently, flexibly and rapidly. These beams can also realize satellite switched time division multiple access (SS-TDMA) communication functions. The hopping spot beam function and SS-TDMA communication systems will be used for broadband communication experiments covering the Asia-Pacific region.

This paper describes the WINDS APAA configuration, in addition to development results and on-board evaluation results of the APAA flight model.

2. APAA Configuration

Figure 1 portrays the APAA configuration. The transmitting and receiving antennas are mounted on the same surface of the APAA Earth panel. All components are mounted in the antenna structure unit, which comprises aluminum honeycomb panels having heat pipes and thermal radiation plates. The APAA dimensions are 1,420 mm × 920 mm × 1,500 mm; its mass is 183 kg. The APAA has a self-controlled thermal dissipation function to maintain a specified temperature range.

Its necessary performance is presented in Table 1. The TX array antenna is a transmitting antenna for the downlink; the RX array antenna is a receiving antenna for the uplink. The Ka-band frequency bandwidth is 1.1 GHz for TX and RX. Each antenna provides two multiple beams for direction within an ellipse, 8 degrees for azimuth and 7 degrees for elevation. Both antennas are designed to provide the specified gain with a minimum number of antenna elements and are designed to avoid grating lobes in the earth surface. Considering these conditions, we used a 128-element array antenna with a triangular lattice. Each element space is 2.7 λ, where λ is the wavelength. A pyramidal horn antenna was adopted as the antenna element because of requirements for a broad bandwidth and high efficiency. The amplitude distributions are uniform to achieve the necessary antenna gain.

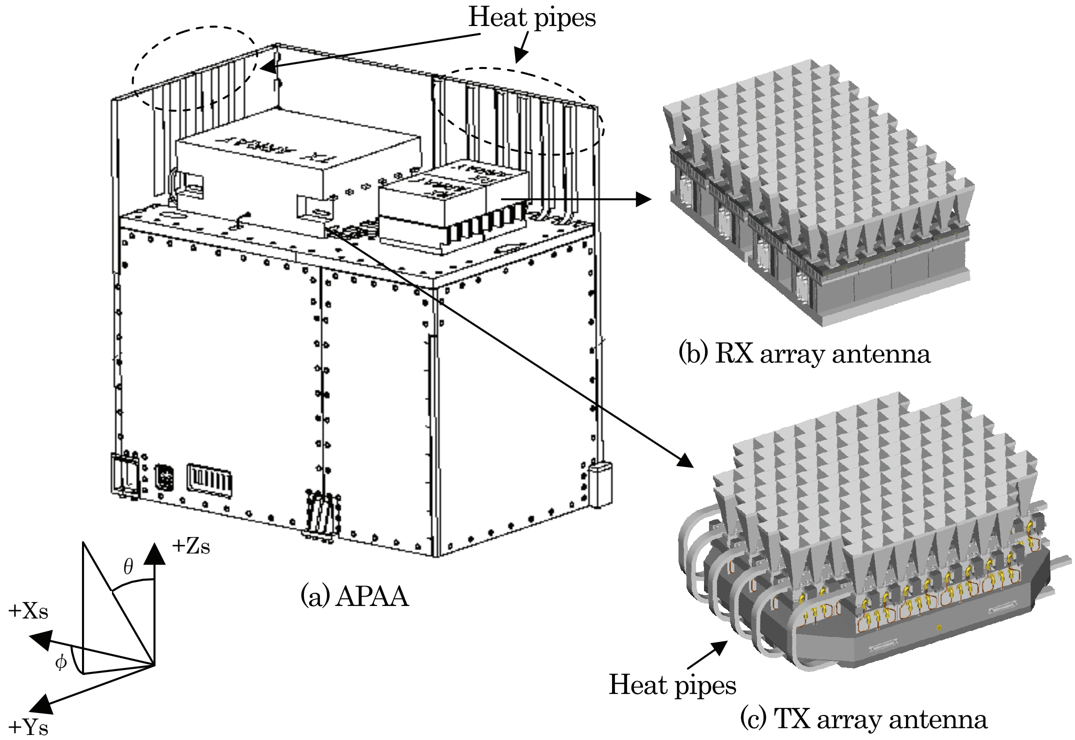


Figure 1: APAA Configuration

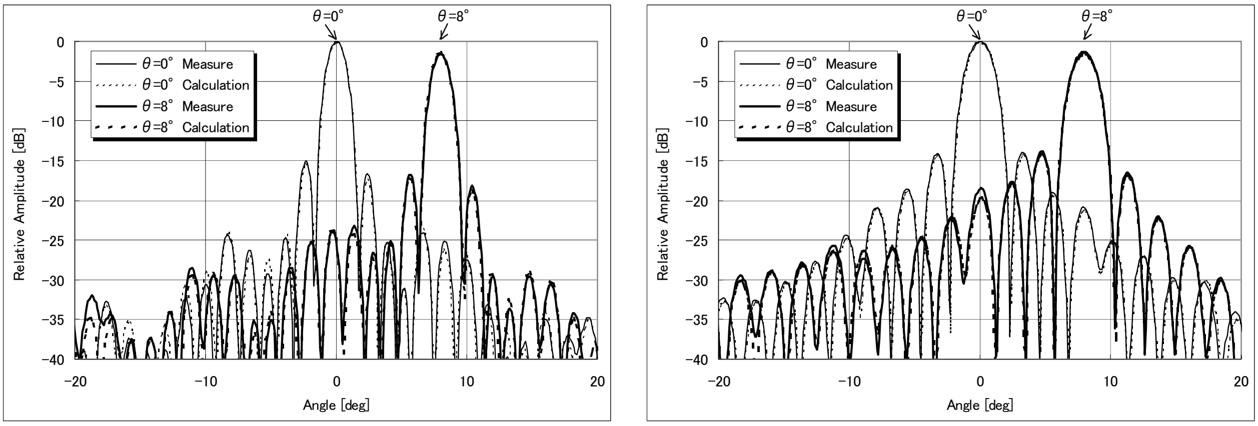
Table 1: APAA Performance

Item	Unit	Performance		Remarks
		TX	RX	
Antenna type	-	Direct radiating phased array antenna		
Aperture size	mm	649×539	287×468	
Frequency band	GHz	18	28	
Frequency bandwidth	GHz	1.1	1.1	
Number of radiation Elements	-	128	128	
Polarization	-	Linear		
Field of view: FOV	deg	Azimuth: 8, Elevation: 7		Ellipse
Number of beams	-	2	2	
Effective isotropically radiated power: EIRP	dBW	≥ 54.6 / 1 beam ≥ 52.1 / 2 beams	-	Beam center in FOV
Antenna gain to noise temperature ratio: G/T	dB/K	-	≥ 7.1	Beam center in FOV
Directive gain	dBi	≥ 37.8	≥ 37.8	at θ = 0
Phase shifter bit number	bit	5	5	Digital phase shifter
Beam hopping time	μs	≤ 10		at SS-TDMA

3. Development results

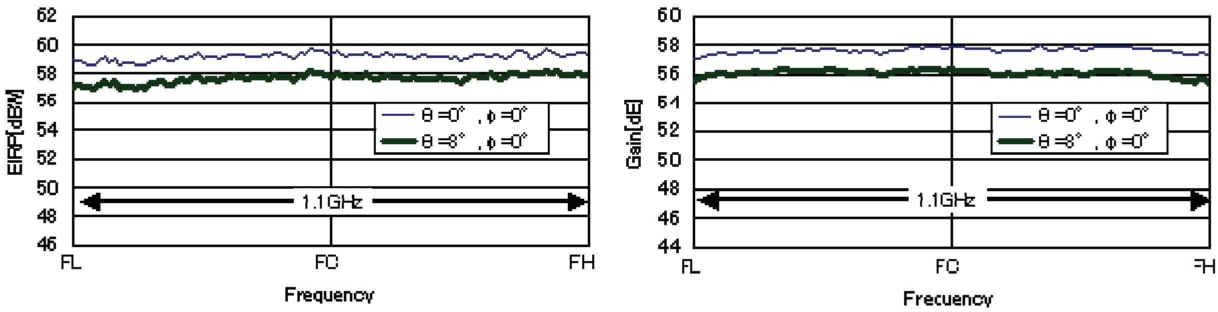
Measured radiation patterns of the APAA flight model are presented in Fig. 2. Good correspondence is shown between measured patterns and calculated ones, enabling confirmation of the performance of the two beams. Actually, EIRP is 56.0 dBW (1 beam) , and G/T is 8.5 dB/K. We also confirmed the beam hopping capability for 2 ms TDMA communication systems and an antenna gain control performance for the gain variation compensation attributable to temperature change.

Figure 3 shows APAA frequency characteristics. The EIRP and RX array antenna gain values in the case of θ = 8 degrees are lower than those in the case of θ = 0 degrees because of the element factor in the APAA. The RX array antenna gain values include the antenna gain and amplifier gain. These values also satisfy APAA performance requirements.



(a) TX Array Antenna (b) RX Array Antenna

Figure 2: Radiation Patterns of Antennas



(a) TX Array Antenna (b) RX Array Antenna

Figure 3: Frequency Characteristics

4. On-board Evaluation results

We tested and evaluated an APAA flight model on the WINDS satellite using some earth stations. We also performed broadband communication experiments using it. Evaluation items are shown below.

(a) APAA functions (beam direction control, beam hopping, antenna gain control, etc.)
(b) APAA specifications (EIRP, G/T, frequency characteristics, main-lobe radiation patterns, etc.)
(c) APAA antenna element performance using REV method [3]

Figure 4 shows an antenna element performance example using the REV method. This test is realized by rotating phase values of each element phase shifter every 80 ms and measuring a receiving signal at an earth station. Results show that all elements have good performance. A broadband communication experiment configuration at a speed of 622 Mbps is presented in Fig. 5. This experiment achieved the fastest speed in the world using an on-board APAA.

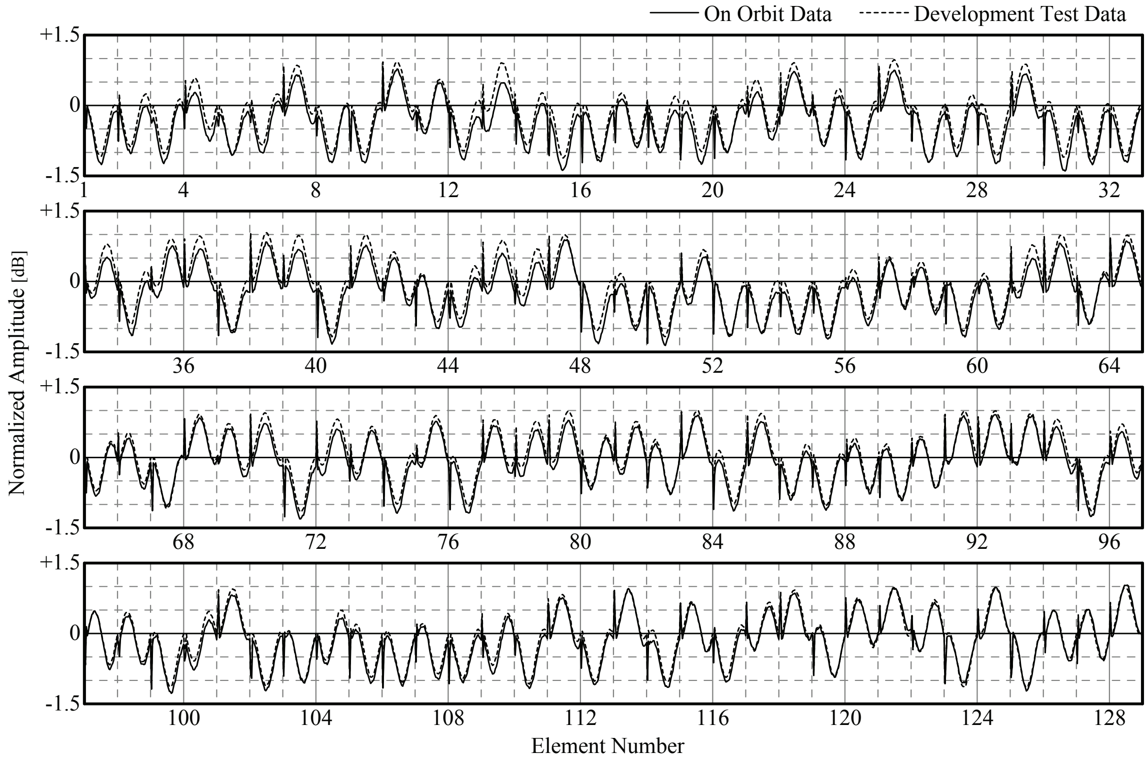


Figure 4: Antenna Element Performance Example Using REV Method

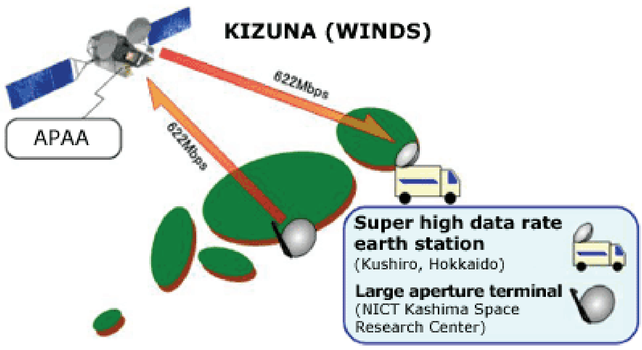


Figure 5: Broadband Communication Experiment Configuration at a Speed of 622 Mbps

5. Conclusion

We describe the WINDS APAA configuration, and development results and on-board evaluation results of the APAA flight model. From the initial evaluation results, we confirmed that the APAA had good performance.

References

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[3] S. Mano, et al: "A Method for Measuring Amplitude and Phase of Each Radiating Element of a Phased Array Antenna", Trans. IEICE, Vol. J65-B, No. 5, pp.555-560, 1982.