3-4 Multibeam Antenna System

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A multibeam antenna system is being developed for mounting on WINDS, the GIGA bit class communication satellite, slated for launch in 2008 by JAXA. This paper describes the RF characteristics of this antenna system.

Keywords
Satellite communications, Wideband InterNetworking Engineering Test and Demonstration Satellite, Ka band, Multibeam antenna system, Satellite development

1 Introduction

A multibeam antenna (MBA) is to be mounted on the Wideband InterNetworking Engineering Test and Demonstration Satellite (WINDS) scheduled for launch in 2008. This antenna makes use of the Ka-band using a multi-port amplifier, and is employed in experiments aimed at demonstrating technologies for the provision of a transmission and reception rate of 1.2 Gbps, as well as guaranteed performance against regional rain attenuation, to an earth station equipped with a 5-m-aperture antenna. Accordingly, the antenna is equipped with multiple beams, one horn per beam, the world's first Ka-band polarization grid, and primary mirrors that maintain high reflective precision in orbit.

This paper presents an overview of the RF characteristics of the MBA, as these relate to the establishment of the WINDS communication system.

2 Specifications

The MBA is a subsystem of WINDS. This antenna is designed for fixed-beam communications and is used with a multi-port amplifier, which comprises another WINDS subsystem. The MBA is designed to provide 1.2-Gbps transmission to an earth station equipped with an antenna featuring an aperture of 5 m, and 155-Mbps transmission to an earth station equipped with an antenna featuring a 45-cm antenna aperture. Table 1 presents the WINDS-based specifications for the fixed beams. The MBA system consists of an MBA for Japan, which covers areas within and near Japan, and an MBA for Southeast Asia, which covers the Asia/Pacific region. As shown in Fig. 1, total MBA coverage includes 19 areas: 12 areas covered by the MBA for Japan and seven areas covered by the MBA for Southeast Asia. Table 2 presents the specifications of the MBA.

3 RF characteristics [1]

3.1 Design

Figure 2 (a) shows the external appearance of the MBA. The MBA mainly consists of two primary mirrors equivalent to a 2.4-m aperture, two secondary mirrors, a polarization grid, and three power-feed units with 19 power-feed horns.

As the MBA structure entails the placement of a number of power-feed horns corresponding to 12 beams within the limited space in the MBA for Japan, a polarization grid structure is employed. Figure 2 (b) shows a schematic diagram of this concept. A polarization grid is an equally spaced parallel grid placed on a dielectric panel with a small absorption rate. Among linearly polarized waves, the polarization grid reflects V-polarized waves, which are components oriented in the direction of the electric field parallel to the grid; and transmits H-polarized waves, which are components oriented in the direction of the electric field perpendicular to the grid. Thus, the power-feed units for the V-polarized waves and H-polarized waves can be placed

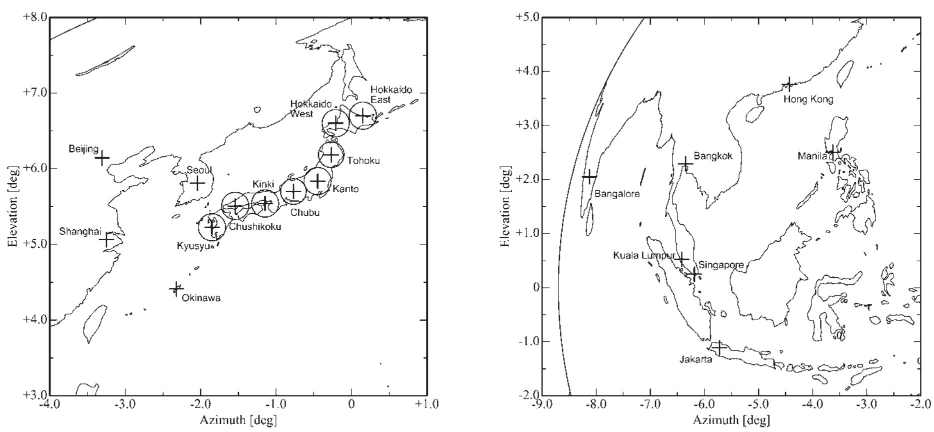
Table 1 *Required Performance for Communications by Fixed Beams*

Item	Value
Frequency Band	
TX	18 GHz
RX	28 GHz
Beam Coverage	(see Figure 1)
Number of Beams	
Japan-MBA	12
Asia-MBA	7
Polarization	Linear
EIRP	
Kyusyu, Kinki, Kanto and Hokkaido West beam	67.9 dBW
Chushikoku, Chubu, Tohoku and Hokkaido East beam	67.6 dBW
Okinawa and other beams	67.3 dBW
G/T	
Kyusyu, Chuchikoku, Kinki, Chubu, Kanto, Tohoku, Hokkaido West and Hokkaido East beam	16.9 dB/K
Okinawa and other beams	16.3 dB/K

Table 2 *Required Performance for Communications by Fixed Beams*

Item	Value
Polarization	
Chushikoku, Chubu, Tohoku, Hokkaido East and Singapore beam	Vertical
Kyusyu, Kinki, Kanto ,Hokkaido West and other beams	Horizontal
TX Antenna Gain *	
Kyusyu, Kinki, Kanto , Hokkaido West beam	45.4 dBi
Chushikoku, Chubu, Tohoku and Hokkaido East beam	45.1 dBi
Okinawa and other beams	44.8 dBi
RX Antenna Gain *	
Kyusyu, Chushikoku, Kinki, Chubu, Kanto, Tohoku, Hokkaido West and Hokkaido East beam	45.9 dBi
Okinawa and other beams	45.3 dBi
Isolation between each beam	25 dB

* Antenna Gain includes Wava Guide Loss



(a) Japan-MBA (B) Asia-MBA

Fig.1 *Coverage of Multi Beam Antenna* on different sides of the grid.

Each power-feed unit has five to seven power-feed horns. Each power-feed horn is placed off-focus. This off-focus placement causes degradation in RF characteristics; as a result, operation of the MBA incorporates the Cassegrain offset method. In this manner, the logical F/D can be set at a relatively large value of 3.4, which reduces degradation in RF performance attributable to the off-focus placement of the horns.

3.2 Peak gains and antenna radiation patterns

We have analyzed the peak gain of each MBA beam. Tables 3 to 6 show analysis results

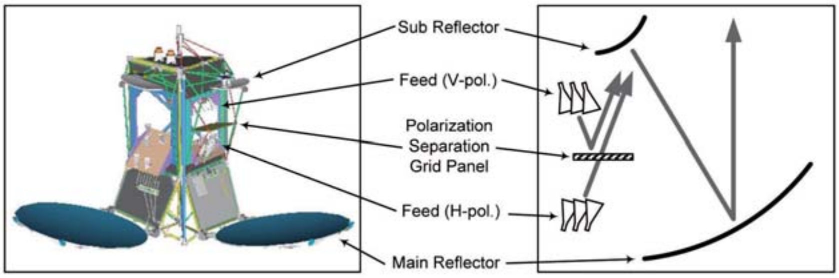


Fig.2 *Overview of Multi Beam Antenna*

Table 3 *Antenna Gain of Japan-MBA (TX)*

Unit : dBi

Beam		Hokkaido West	Kanto	Kinki	Kyusyu	Seoul	Beijing	Shanghai	Hokkaido East	Tohoku	Chubu	Chu-shikoku	Okinawa
Polarization		H	H	H	H	H	H	H	V	V	V	V	V
Antenna Gain at Beam Point (Analytic)	17.70 GHz	51.4	51.4	51.4	51.4	49.4	49.6	50.8	51.3	51.2	51.2	51.3	51.1
	18.25 GHz	51.7	51.7	51.7	51.7	49.8	50.0	51.1	51.6	51.5	51.5	51.6	51.4
	18.80 GHz	52.0	52.0	52.0	52.0	50.2	50.3	51.4	51.9	51.8	51.8	51.9	51.7
Antenna Gain in Beam Area (Analytic)	17.70 GHz	49.4	49.3	49.3	49.3	-	-	-	49.3	49.2	49.2	49.2	-
	18.25 GHz	49.6	49.5	49.5	49.5	-	-	-	49.5	49.4	49.4	49.4	-
	18.80 GHz	49.8	49.7	49.7	49.7	-	-	-	49.7	49.6	49.6	49.6	-
Antenna Gain at Beam Point (including loss)	17.70 GHz	47.8	47.8	47.8	47.8	45.8	45.8	47.2	47.4	47.3	47.3	47.4	47.5
	18.25 GHz	48.1	48.1	48.1	48.1	46.2	46.2	47.5	47.7	47.6	47.6	47.7	47.8
	18.80 GHz	48.4	48.4	48.4	48.4	46.6	46.5	47.8	48.0	47.9	47.9	48.0	48.1
Antenna Gain in Beam Area (including loss)	17.70 GHz	45.8	45.7	45.7	45.7	-	-	-	45.4	45.3	45.3	45.3	-
	18.25 GHz	46.0	45.9	45.9	45.9	-	-	-	45.6	45.5	45.5	45.5	-
	18.80 GHz	46.2	46.1	46.1	46.1	-	-	-	45.8	45.7	45.7	45.7	-
Antenna Gain (Specific)		45.4 (in Beam Area)				44.8 (at Beam Point)			45.1 (in Beam Area)				44.8 (at B.Pt.)

Table 4 *Antenna Gain of Japan-MBA (RX)*

Unit : dBi

Beam		Hokkaido West	Kanto	Kinki	Kyusyu	Seoul	Beijing	Shanghai	Hokkaido East	Tohoku	Chubu	Chu-shikoku	Okinawa
Polarization		H	H	H	H	H	H	H	V	V	V	V	V
Antenna Gain at Beam Point (Analytic)	27.50 GHz	54.3	54.4	54.5	54.4	54.2	53.0	53.7	54.2	54.7	54.7	54.2	53.7
	28.05 GHz	54.4	54.5	54.5	54.5	54.4	53.0	53.7	54.3	54.8	54.8	54.3	53.7
	28.60 GHz	54.5	54.5	54.6	54.5	54.5	53.1	53.8	54.3	54.9	54.9	54.3	53.7
Antenna Gain in Beam Area (Analytic)	27.50 GHz	52.0	51.9	51.9	51.9	-	-	-	50.5	50.2	50.1	50.2	-
	28.05 GHz	52.0	51.9	51.9	51.9	-	-	-	50.4	50.2	50.1	50.1	-
	28.60 GHz	52.0	51.9	51.9	51.8	-	-	-	50.4	50.2	50.1	50.1	-
Antenna Gain at Beam Point (including loss)	27.50 GHz	48.8	48.9	48.9	48.8	48.7	47.4	48.2	50.2	50.7	50.7	50.2	49.6
	28.05 GHz	48.9	48.9	49.0	49.0	48.8	47.5	48.2	50.2	50.8	50.8	50.2	49.7
	28.60 GHz	48.9	49.0	49.0	48.8	48.9	47.5	48.2	50.2	50.8	50.8	50.3	49.7
Antenna Gain in Beam Area (including loss)	27.50 GHz	46.5	46.3	46.4	46.3	-	-	-	46.4	46.2	46.1	46.1	-
	28.05 GHz	46.5	46.3	46.3	46.3	-	-	-	46.4	46.1	46.1	46.1	-
	28.60 GHz	46.4	46.3	46.3	46.3	-	-	-	46.3	46.1	46.0	46.0	-
Antenna Gain (Specific)		45.9 (in Beam Area)				45.3 (at Beam Point)			45.9 (in Beam Area)				45.3 (at B.Pt.)

Table 5 Antenna Gain of Asia-MBA (TX)

Unit : dBi

Beam		Manila	Hong Kong	Bangkok	Bangalore	Jakarta	Kuala Lumpur	Singapore
Polarization		H	H	H	H	H	H	V
Antenna Gain at Beam Point (Analytic)	17.70 GHz	49.7	49.4	51.1	50.7	50.3	48.2	48.3
	18.25 GHz	50.0	49.7	51.4	51.0	50.6	48.6	48.8
	18.80 GHz	50.2	49.9	51.7	51.3	50.8	49.0	49.2
Antenna Gain at Beam Point (including loss)	17.70 GHz	46.6	46.3	48.0	47.6	47.2	45.1	45.2
	18.25 GHz	46.9	46.6	48.3	47.9	47.5	45.5	45.7
	18.80 GHz	47.1	46.8	48.6	48.2	47.7	45.9	46.1
Antenna Gain (Specific)		44.8						

Table 6 Antenna Gain of Asia-MBA (RX)

Unit : dBi

Beam		Manila	Hong Kong	Bangkok	Bangalore	Jakarta	Kuala Lumpur	Singapore
Polarization		H	H	H	H	H	H	V
Antenna Gain at Beam Point (Analytic)	27.50 GHz	52.0	51.7	54.2	53.8	53.4	53.2	53.6
	28.05 GHz	51.9	51.7	54.3	53.9	53.5	53.3	53.8
	28.60 GHz	51.9	51.7	54.4	54.0	53.6	53.5	54.0
Antenna Gain at Beam Point (including loss)	27.50 GHz	48.4	48.1	50.7	50.3	49.9	49.6	50.1
	28.05 GHz	48.4	48.1	50.7	50.3	50.0	49.8	50.3
	28.60 GHz	48.4	48.1	50.8	50.4	50.1	50.0	50.5
Antenna Gain (Specific)		45.3						

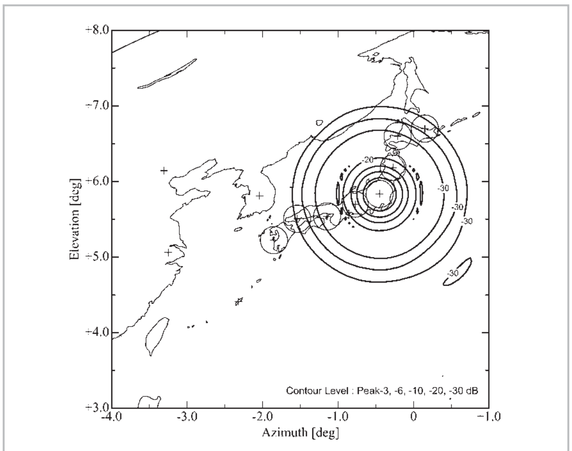


Fig.3 Antenna Gain Contours of Kanto Beam (TX)

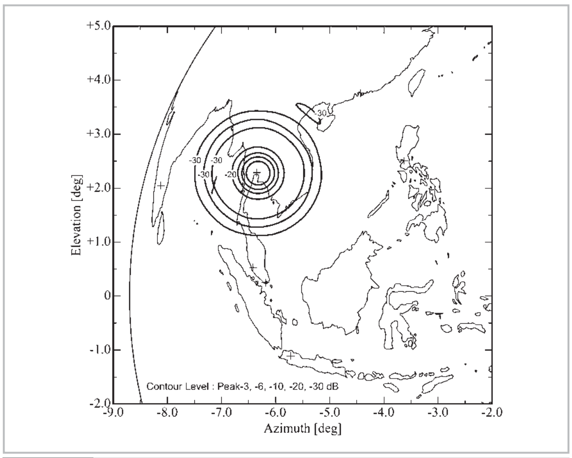


Fig.5 Contours of Bangkok Beam (TX)

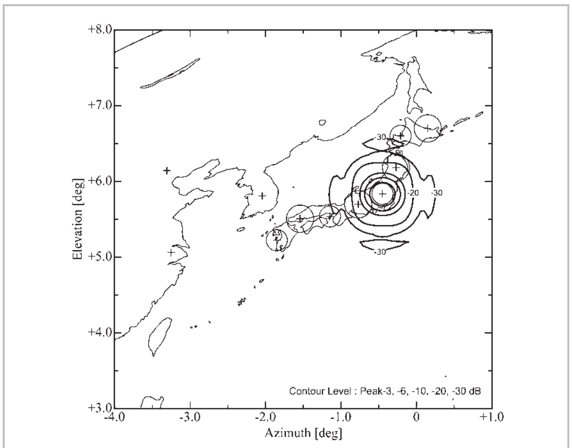


Fig.4 Antenna Gain Contours of Kanto Beam (RX)

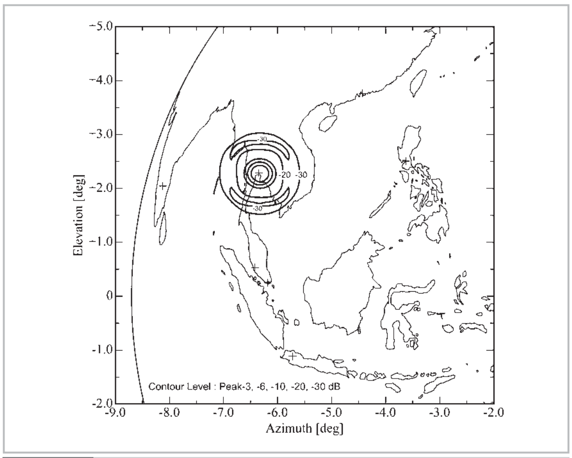


Fig.6 Contours of Bangkok Beam (RX)

for peak gain of the transmission beams of the MBA for Japan, the receiving beams of the MBA for Japan, the transmission beams of the MBA for Southeast Asia, and the receiving beams of the MBA for Southeast Asia, respectively. These tables confirm that the MBA satisfies the required peak gain values. We have also analyzed the antenna radiation patterns. As a representative example, Figs. 3 to 6 show the results of antenna-radiation pattern analyses for the Kanto transmission beam, Kanto receiving beam, Bangkok transmission beam, and Bangkok receiving beam, respectively.

3.3 Isolation

The MBA specifies inter-beam isolation. Figure 7 illustrates the concept of inter-beam isolation for the transmission beams. We evaluated inter-beam isolation for transmission beams by calculating the difference, I_t dB, between the antenna pattern of the desired beam, X_d dBi, and the antenna pattern of the interference beam, X_i dBi, and creating a pattern of the isolation, I_t. Figure 7 shows the isolation pattern for the Kanto transmission beam as an example. Figure 8 similarly shows the concept of inter-beam isolation between the receiving beams. We evaluated inter-beam isolation for the receiving beams by calculating the difference, I_r dB, between the antenna gain of the desired beam at the edge of the radiation range, X_d dBi, and the antenna pattern of the desired beam in the radiation range, X_i dBi, and the generated pattern of the isolation, I_r. Figures 9 and 10 show the isolation patterns of the Kanto receiving beam as examples. These analyses confirm that the MBA satisfies the relevant inter-beam isolation specifications. Tables 7 to 10 show the specified values of inter-beam isolation.

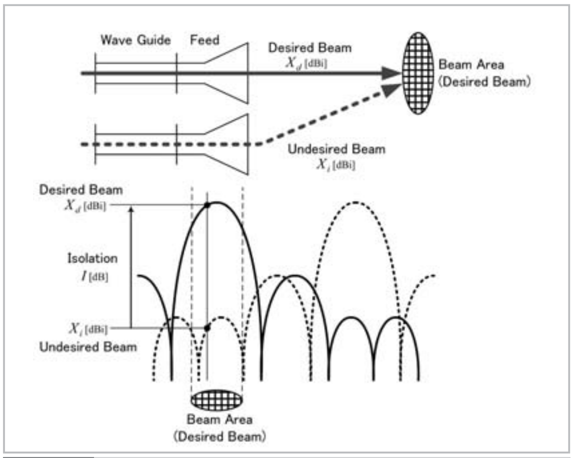


Fig.7 Isolation between each beams (TX)

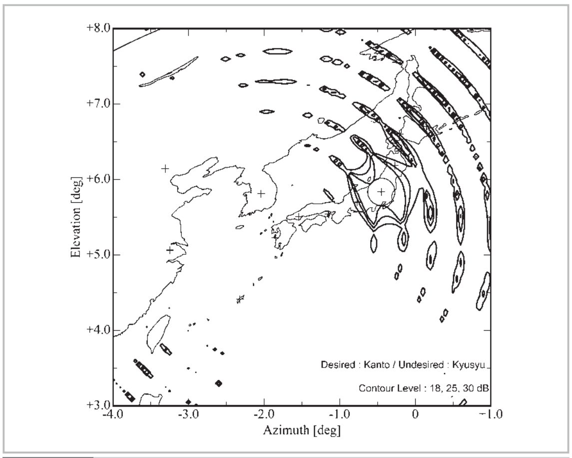


Fig.9 Analysis Result of Isolation (TX)

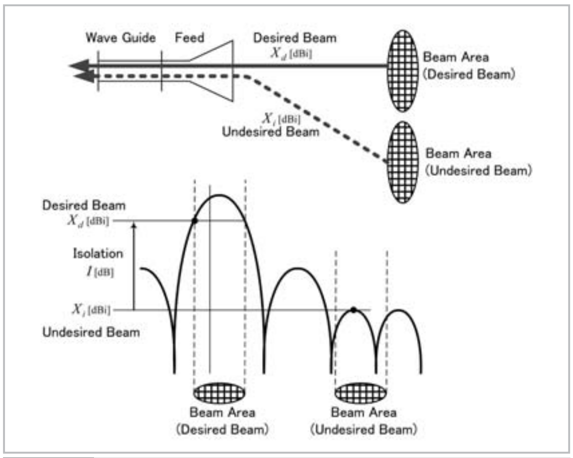


Fig.8 Isolation between each beams (RX)

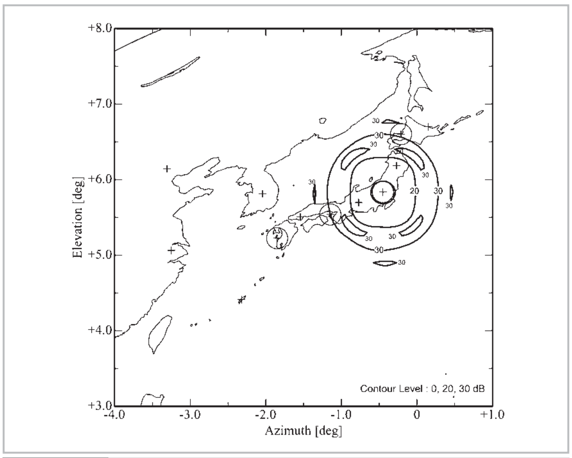


Fig.10 Analysis Result of Isolation (RX)

Table 7 Specific Isolation between each beams (Japan-MBA TX)

Unit : dB

Undesired Beam \ Desired Beam	Hokkaido East	Hokkaido West	Tohoku	Kanto	Chubu	Kinki	Chu-shikoku	Kyusyu	Okinawa	Seoul	Beijing	Shanghai
Hokkaido East		25	N/A	30	18	30	25	30	25	30	30	30
Hokkaido West	25		25	N/A	30	18	30	25	30	25	25	25
Tohoku	N/A	25		25	N/A	30	18	30	25	30	30	30
Kanto	30	N/A	25		25	N/A	30	18	30	20	25	25
Chubu	18	30	N/A	25		25	N/A	30	25	30	30	30
Kinki	30	18	30	N/A	25		25	N/A	30	N/A	25	25
Chu-shikoku	25	30	18	30	N/A	25		25	18	25	30	30
Kyusyu	30	25	30	18	30	N/A	25		30	N/A	20	16
Okinawa	25	30	25	30	25	30	18	30		30	30	30
Seoul	30	25	30	20	30	N/A	25	N/A	30		18	20
Beijing	30	25	30	25	30	25	30	20	30	18		16
Shanghai	30	25	30	25	30	25	30	16	30	20	16	

Table 8 Specific Isolation between each beams (Japan-MBA RX)

Unit : dB

Undesired Beam \ Desired Beam	Hokkaido East	Hokkaido West	Tohoku	Kanto	Chubu	Kinki	Chu-shikoku	Kyusyu	Okinawa	Seoul	Beijing	Shanghai
Hokkaido East		25	N/A	30	25	30	25	30	25	30	30	30
Hokkaido West	25		25	N/A	30	25	30	25	30	25	25	25
Tohoku	N/A	25		25	N/A	30	25	30	25	30	30	30
Kanto	30	N/A	25		25	N/A	30	25	30	25	25	25
Chubu	25	30	N/A	25		25	N/A	30	25	30	30	30
Kinki	30	25	30	N/A	25		25	N/A	30	N/A	25	25
Chu-shikoku	25	30	25	30	N/A	25		25	25	25	30	30
Kyusyu	30	25	30	25	30	N/A	25		30	N/A	25	20
Okinawa	25	30	25	30	25	30	25	30		30	30	30
Seoul	30	25	30	25	30	N/A	30	N/A	30		20	20
Beijing	30	25	30	25	30	25	30	25	30	20		20
Shanghai	30	25	30	25	30	25	30	20	30	20	20	

Table 9 Specific Isolation between each beams (Asia-MBA TX)

Unit : dB

Undesired Beam \ Desired Beam	Manila	Hong Kong	Bangkok	Bangalore	Jakarta	Singapore	Kuala Lumpur
Manila		25	25	25	25	25	30
Hong Kong	25		25	25	25	25	30
Bangkok	25	25		25	25	25	30
Bangalore	25	25	25		25	25	30
Jakarta	25	25	25	25		25	30
Singapore	25	25	25	25	25		25
Kuala Lumpur	30	30	30	30	30	25	

Table 10 *Specific Isolation between each beams (Asia-MBA RX)*

Unit : dB

		Desired Beam						
		Manila	Hong Kong	Bangkok	Bangalore	Jakarta	Singapore	Kuala Lumpur
Undesired Beam	Manila		25	25	25	25	25	30
	Hong Kong	25		25	25	25	25	30
	Bangkok	25	25		25	25	25	30
	Bangalore	25	25	25		25	25	30
	Jakarta	25	25	25	25		25	30
	Singapore	25	25	25	25	25		25
	Kuala Lumpur	30	30	30	30	30	25	

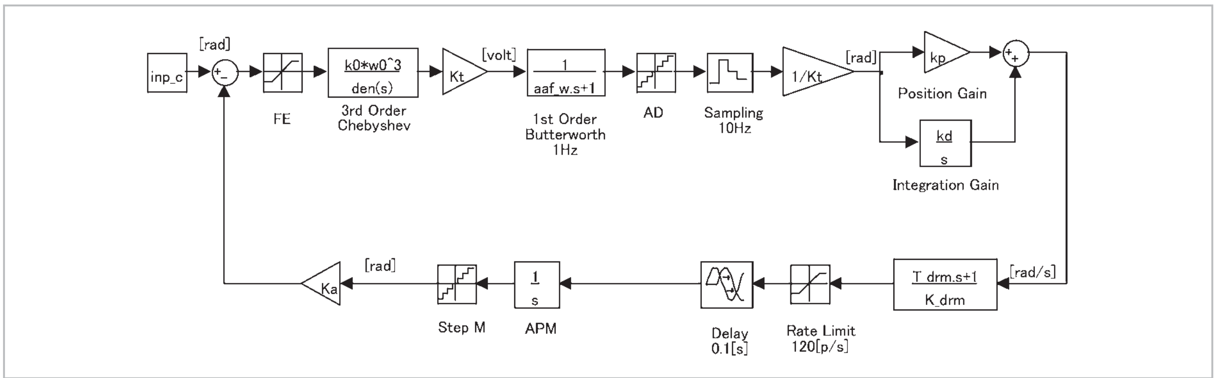


Fig.11 *Block Diagram of Antenna Pointing System*

4 Pointing control [2]

4.1 Design

The error in beam direction that occurs in orbit is corrected by an antenna pointing control system consisting of a tracking receiver, an antenna pointing control mechanism, and secondary mirrors. Figure 11 shows a block line diagram of the antenna pointing control system.

4.2 Beam pointing control for the MBA for Japan

The directions of the 12 beams corresponding to the MBA for Japan are controlled based on beacon signals from Okinawa. The specification for the MBA for Japan governing precision of the pointing control system, excluding mechanical pointing errors, is stipulated as 0.005° in the stationary state. Figure 12 shows the results of simulation of the pointing control system in the stationary state. These results confirm that the precision of the pointing control system satisfies the specifications.

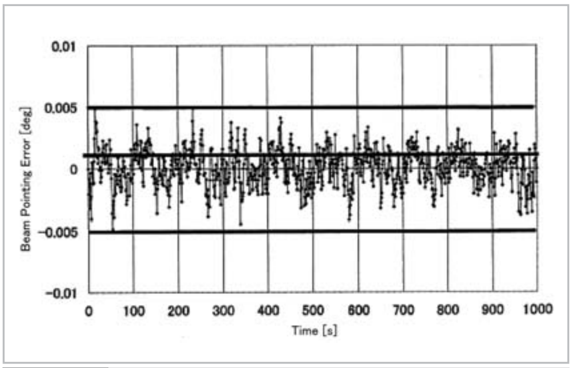


Fig.12 *Simulation Result for Antenna Pointing System*

4.3 Beam pointing control for the MBA for Southeast Asia

The directions of the beams corresponding to the MBA for Southeast Asia are controlled based on a one-day beam pointing history estimated by 24-hour scanning. As shown in Fig. 13, the scan measures the gain by controlling the secondary mirror so that the mirror can move vertically and horizontally by using the driving mechanism. The scan width is approximately ± 0.4°, and the antenna gain is within the range of approximately −5 dB. Using the obtained gain, we approximate the antenna pattern as

$$A = A_0 + c_1 x + c_2 y + c_3 x^2 + c_4 y^2 + c_5 xy + c_6 x^3 + c_7 y^3 + c_8 x^2 y + c_9 xy^2$$

and estimate the direction of peak gain. Here, P [dB] is the gain, and x [rad] and y [rad] are parameters indicating the directions of Az and El, respectively. This estimation is performed at intervals of 5 minutes, and a 24-hour beam pointing history is then estimated. Based on the obtained beam pointing history, pointing control is performed for a period of approximately one week. Analysis confirms that the pointing precision obtained based on this method is within 0.042°.

4.4 Beam direction error and amount of gain depression

The total beam pointing error is 0.031° when inter-beam deviation is considered in addition to beam pointing precision. In terms of coverage with the MBA for Japan, we have taken into particular consideration gain depression at the coverage edge due to beam direction error. Figure 14 illustrates the concept of gain depression. The gain depression thus arising is 1.68 dB in transmission and 3.52 dB in receiving, at maximum.

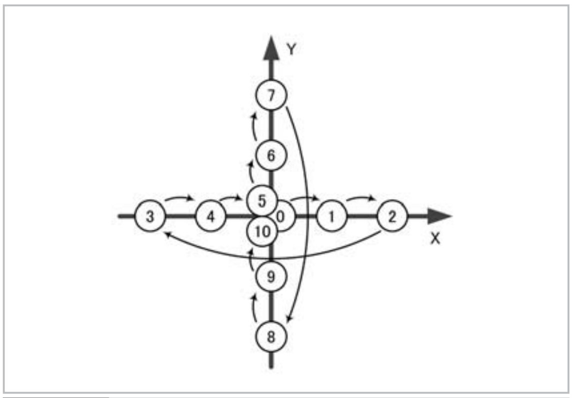


Fig.13 *Scanning Sequence of Asia-MBA*

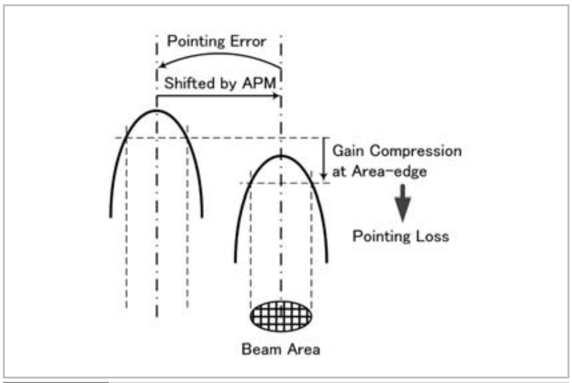


Fig.14 *Pointing Loss caused by Beam Pointing Error*

5 Conclusions

This paper outlines the RF characteristics of the MBA, which provide the basis for the WINDS communication system.

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