DEVELOPMENT RESULTS OF KA-BAND MULTIBEAM ACTIVE PHASED ARRAY ANTENNA FOR GIGABIT SATELLITE

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1. INTRODUCTION

Recently, many Ka-band satellite communication systems with high data rate have been proposed for future global satellite communication services. CRL also proposes gigabit satellite communication system, which can achieve the transmission rate of more than 1.2 Gbps. This satellite is planned to be launched as an experimental satellite in around 2005 and the basic study for this program has been proceeded [1]-[7]. For the full range connectivity all over the world, a Ka-band SSBA is required to realize high EIRP and G/T, for multiple international service areas. A direct radiating APAA are investigated and developed for communication satellite which can operate under wide frequency band in Ka-band [5]-[7].

An APAA applied for the SSBA realizes flexible multiple beam forming as one of the most important and challenging technology in this program. The key features about the development of APAA are minimizing number of element, development of RF components operated in the wide bandwidth, optimization of aperture distribution considering low sidelobe level for beam-to-beam isolation, and MMIC devices and high density packages for miniaturize and light weight performance.

This paper describes the design and development results of Ka-band APAA for Gigabit Satellite and radiation performances of the bread board model of Ka-band APAA with four multiple beams.

2. SATELLITE ANTENNA CONFIGURATION

The SSBA of Gigabit Satellite consists of two identical Ka-band APAAs; one is a transmitting APAA for down link, and the other is a receiving APAA for up link. The Ka-band frequency bandwidth is 5% centered at 18.25 GHz for transmitting and 4% centered at 28.05 GHz for receiving. Four multiple beams are required and the required gain is approximately 46.4dBi. Aperture diameters of the antenna were designed to be 2.2m for transmit and 1.5m for receive, respectively [1] [5]. The satellite is considered that the both antennas are mounted on the same surface of the satellite's earth panel without deployable structure to simplify the thermal control. The element spacing is decided by the beam-scanning angle to restrict the grating-lobe generation in the field of view. The scanning angle is required within ±8 degrees. This makes element spacing 2.2 times of the wavelength. As the result, the element number was determined around 2200 with aperture diameter 2.2 m for transmitting antenna and 1.5 m for receiving antenna, respectively. The radiating performance of the APAA is also controlled by the aperture distribution to achieve the required isolation between each beam. The thinned array element arrangement is adopted. To keep the antenna directivity of more than 46.4 dBi, the number of the transmitting and receiving active modules is designed to be approximately 1900 to suppress the sidelobe level less than -20 dB.

Figure 1 shows the antenna configuration of the APAA. This APAA consists of 38 subarray unit and the subarray unit consists of 64 (8x8) antenna elements. The subarray is composed of POL (polarizer), ANT (radiating element), HPA(High Power Amplifier) / LNA(Low Noise Amplifier), BFN (Beam Forming Network) with DIV (Divider), COMB (Combiner), PS (Phase Shifter) and VDL (Variable Delay Line) for four independent beams, power supply and beam controller. To realize high-density module packaging, active devices have been developed in the P-HEMT MMIC technology . HPA is designed more than 20% of PAE (Power Added Efficiency) at operating level to achieve 200W total output. LNA is designed less than 3.5dB N/F. PS consists of 5 bit to achieve sidelobe level less than -20dB. A multi-layered DIV/COMB substrate with four beams is also applied to miniaturize the package size.

3. DEVELOPMENT OF BREAD BOARD MODEL APAA

3.1. ANTENNA CONFIGURATION

The breadboard models of Ka-band APAA with four multiple beams have been developed for both transmit and receive antennas as shown in the Figure 2. The block diagrams of those models are shown in the Figure 3. The performance summary of those models is shown in the Table 1. Those models have been developed to evaluate the basic radiation performances such as beam scanning characteristics, multi-beam performances, and frequency characteristics of amplifier and beam control method (REV :Rotating Element electric-field Vector Method)[8]. Additionally, those models have been designed to realize subarray unit of the antenna configuration in Figure 1. Both of transmitting and receiving APAAs are composed of 64(8x8) radiating element. The element spacing of this breadboard model has been determined approximately 2.2 λ . The active devices such as HPA, LNA and PS have been developed with the MMIC technology.

3.2. RADIATION PERFORMANCE

The performance of the breadboard model was measured for the transmitting and the receiving antenna. The radiation performances such as radiation pattern and beam scanning capability have been measured. Measured radiation patterns are shown in the Figure 4.

Axial ratio of the meanderline polarizer was less than 2.0 dB in the required frequency band for transmitting and receiving antennas, respectively.

For the APAA with many active modules, it is important to evaluate the amplitude and phase of each module. To correct these deviations due to the manufacturing tolerance, the amplitude and phase of each radiating element must be accurately measured in the system test and the phase deviations can be corrected by the phase shifters that are included in the APAA. To simplify the APAA, it is adopted that the radiation pattern of a large aperture APAA is corrected by using the REV method. The REV method enables us to know the excitation amplitude and phase of each element by observing the amplitude variation of the composite electrical field in the array operation when phase shifter rotates the electric field of each element.

In this breadboard model, the REV method has also been verified for both transmitting and receiving APAAs. Figure 5 shows the comparison of the radiation performance between non-calibration and REV calibration. The radiation pattern calibrated by the REV method can be formed to the desired radiation direction, and we confirmed the effectiveness of the REV method. This method will be especially effective when number of the element increases.

In the APAA required to operate in the wide scanning frequency bandwidth more than 1GHz, beam shift within the bandwidth is produced by phase excitation. So the phase shifter is required to have true time delay performance that the amount of phase shift is in proportion of the frequency. We could confirm the true time delay beam scannning performance in each frequency by this bread board model APAA.

4. CONCLUSION

The direct radiating APAA was adopted to realize high EIRP and G/T for Gigabit satellite. In this system, the REV method and the true time delay beam control are adopted to obtain the desired beam-scanning characteristic.

The breadboard models of Ka-band APAA with four multiple beams have been developed and measured for both transmitting and receiving sub array antennas which consist of 64 radiating elements.

We could verified that the full scale SSBA can be developed based on this BBM development result, and the effectiveness of REV method and true time delay performance has been also confirmed in this breadboard model.

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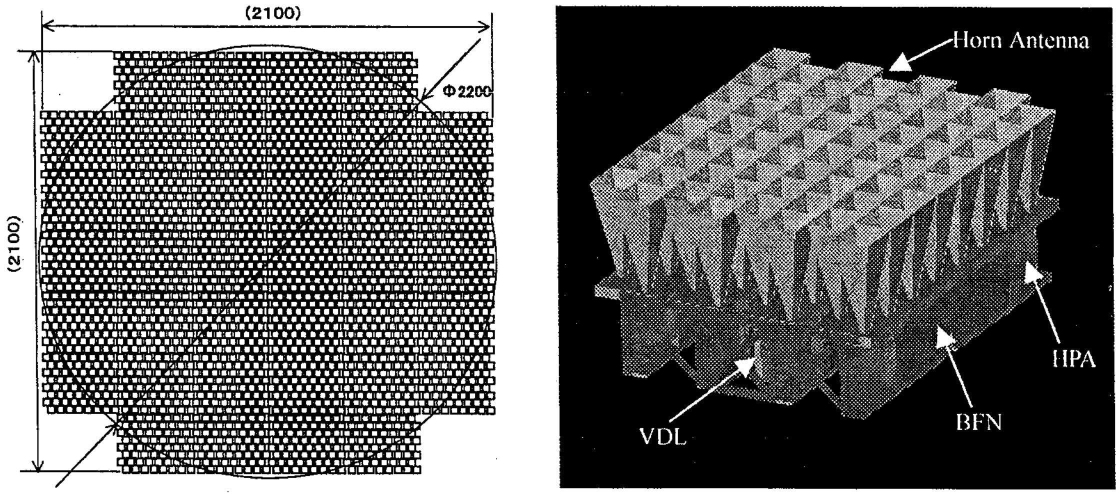
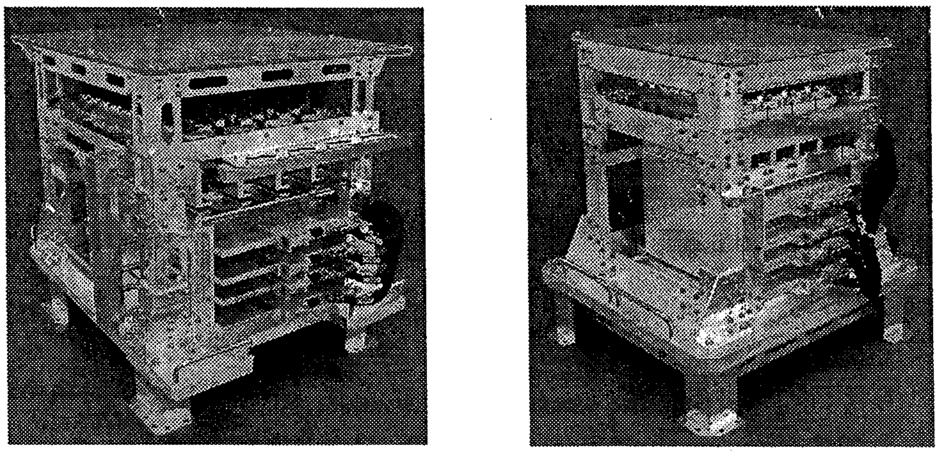


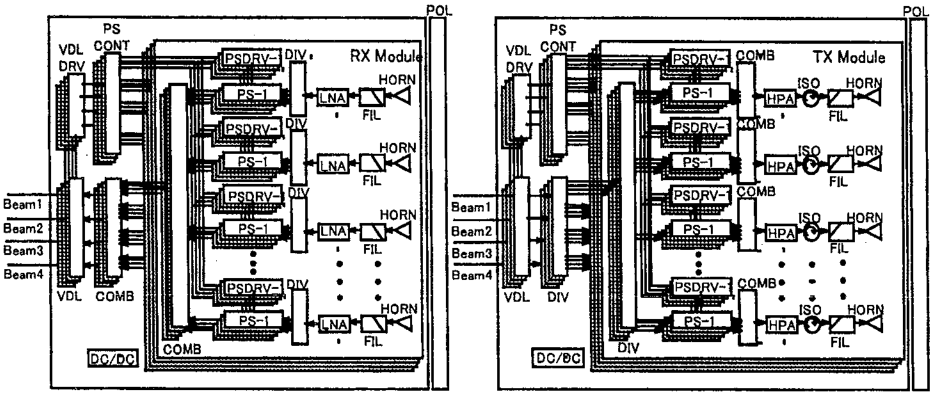
(a) Antenna Aperture (38 Subarray Unit) (b) Subarray Unit
Figure1.Antenna Configuration of the APAA (Transmitting)



(a) Transmitting APAA (b) Receiving APAA
Figure 2 Photograph of Bread Board Model APAA

Table 1. Performance Summary of Bread Board Model APAA

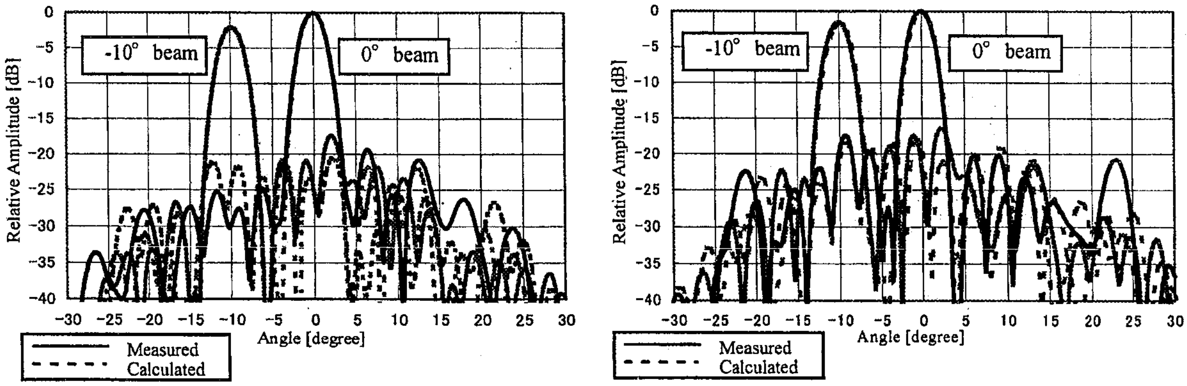
Items	Down-link(Transmit)	Up-link(Receive)	Remarks
Frequency	17.7-18.8 GHz	27.5-28.6 GHz	
Number of Beams	4	4	
Number of Element	64	64	
Phase Shifter Bit Number	5	5	Digital Phase shifter
Axial Ratio	1.4 dB	2.0 dB	at 0degree
NPR	-15 dBc	N/A	
Output Power / HPA	25.9 dBm	N/A	Satulation
	23.4 dBm	N/A	NPR(-15 dBc)
Noise Figure / LNA	N/A	3.6 dB	
Directive Gain	32.4 dBi	32.4 dBi	at 0degree



POL	: Polarizer
HORN	: Horn Antenna
FIL	: Filter
ISO	: Isolator
HPA	: High Power Amplifier
LNA	: Low Noise Amplifier
DIV	: Power Divider
COMB	: Power Combiner
PS	: Phase Shifter
PSDRV	: PS Driver
PSCONT	: PS Controller
DC/DC	: DC/DC Converter

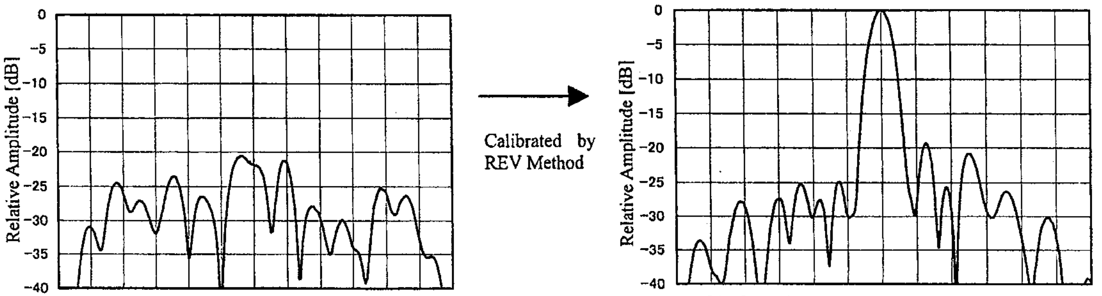
(a) Transmit (b) Receive

Figure3 Block Diagram of Bread Board Model APAA



(a)Transmit APAA(ϕ =0 degree) (b)Receive APAA(ϕ =0 degree)

Figure 4 Radiation Pattern of Bread Board Model APAA



(a) Radiation Pattern with all PS set 0 degree (measured before Pattern Calibration)

(b) Radiation Pattern Calibrated by REV Method (measured)

Figure 5 Radiation Pattern Comparison