Objectives and Characteristics of the Spaceborne Dual Frequency Precipitation Radar for GPM

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***Abstract*— The Dual-frequency Precipitation Radar (DPR) installed on the Global Precipitation Measurement (GPM) core satellite is being developed by JAXA and NICT. This paper describes the mission objectives, the precipitation measurement method and techniques, and the construction of the DPR.**

Keywords-GPM; DPR; precpitation measurement

I. INTRODUCTION

The Dual-frequency Precipitation Radar (DPR) on the Global Precipitation Measurement (GPM) core satellite is being developed by JAXA and NICT. The GPM is a follow-on mission of the Tropical Rainfall Measuring Mission (TRMM). The objectives of the GPM program are to observe global precipitation more frequently and accurately than TRMM. The frequent precipitation measurement every three hours will be achieved by eight constellation satellites with microwave radiometers (MWRs), which will be developed by various countries. The accurate measurement of precipitation from tropics to mid-high latitudes will be achieved by the DPR. The GPM core satellite is jointly developed with NASA. NASA is developing the satellite bus and the GPM Microwave Imager (GMI), and JAXA and NICT are developing the DPR. Figure 1 shows the external image of the GPM core satellite. This paper describes how DPR achieves the objectives of GPM using the dual-frequency precipitation method and techniques, and the features of the construction of the DPR.

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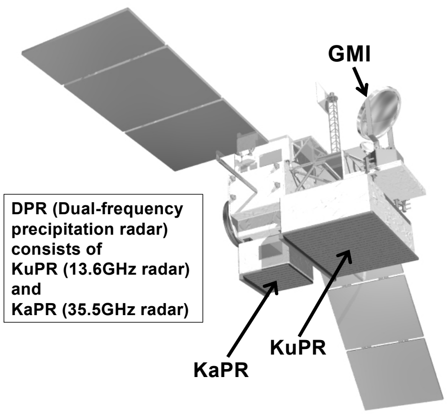

Figure 1. External Image of GPM Core Satellite

II. OBJECTIVES

Figure 2 shows the concept of precipitation measurement with GPM core satellite.

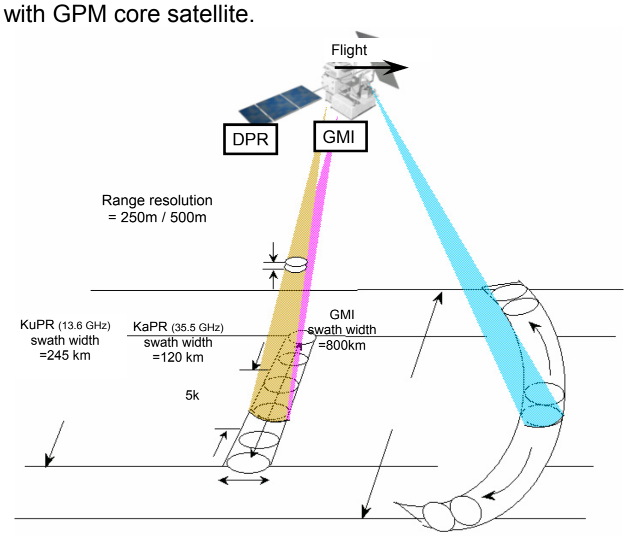

Figure 2. Concept of precipitation measurement with GPM core satellite

The configuration of precipitation measurement using an active radar and a passive radiometer is similar to TRMM. The inclination of the core satellite is 65 degrees, and the flight altitude is about 407 km. The non-sun-synchronous circular orbit is necessary for measuring the diurnal change of rainfall. This is also similarly to TRMM. The DPR consists of the two radars, which are Ku-band (13.6 GHz) precipitation radar (KuPR) and Ka-band (35.5 GHz) radar (KaPR). The objectives of the DPR are (1) to provide three-dimensional precipitation structure including snowfall over both ocean and land, (2) to improve the sensitivity and accuracy of precipitation measurement, (3) to calibrate the precipitation amount estimated by MWRs on the constellation satellites. Figure 3 shows the concept of dual-frequency measurement of precipitation. Because of the difference

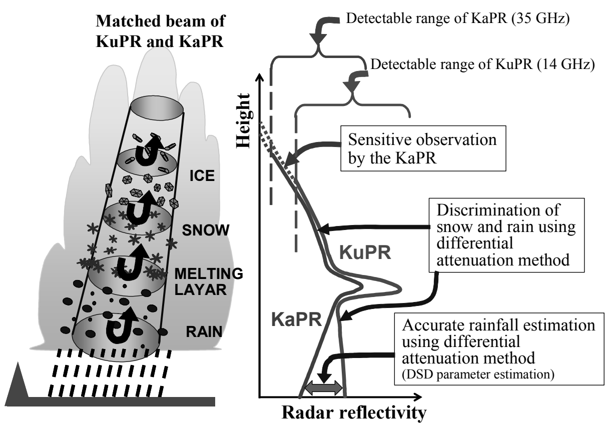

Figure 3. Concept of dual-frequency measurement of precipitation

in the detectable dynamic ranges of KuPR and KaPR, the KaPR can measure snow and light rain, and the KuPR can measure heavy and moderate rain. In an overlapped dynamic range in both KuPR and KaPR, drop size distribution (DSD) information and more accurate rainfall estimates will be provided by a dual-frequency algorithm [1]. The dual-frequency algorithm must use the difference in rain attenuation from the matched beam data observed by KuPR and KaPR. The DPR will provide a global database of precipitation characteristics, such as heights, freezing levels, DSDs, the mean structure of precipitation profiles and others. This database is useful in improving the MWR algorithm.

III. CONSTRUCTION

Figure 4a and 4b show the internal structures and the dimensions of KuPR and KaPR. Both KuPR and KaPR have almost the same designs as the TRMM PR. Each radar has 128 slot array antenna elements, transmitters (Solid State Power Amplifier: SSPA), receivers (Low Noise Amplifier: LNA), Phase Shifters (PHS), and other components. Frequency Converter Intermediate Frequency unit (FCIF) and System Control Data Processing unit (SCDP) of both KuPR and KaPR have almost the same designs. To decrease the mass of KuPR and KaPR, one SCDP is installed on KuPR which is used to control both KuPR and KaPR. Also we maintain the redundancy by installing another SCDP in KaPR. Table I shows the main characteristics of the DPR. The beam widths of both KuPR and KaPR are 0.7

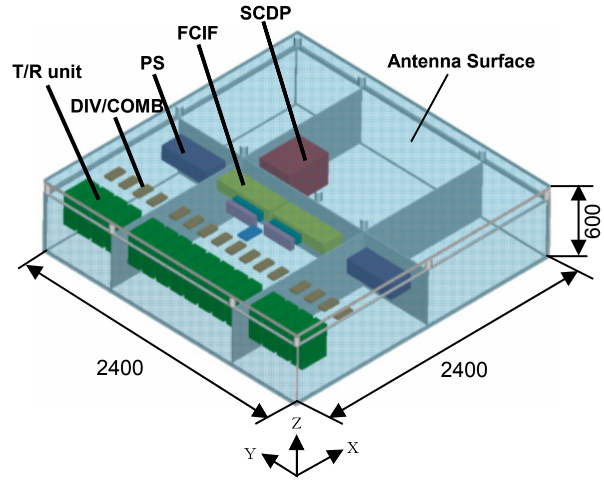

Figure 4a. Internal structure and dimensions of KuPR

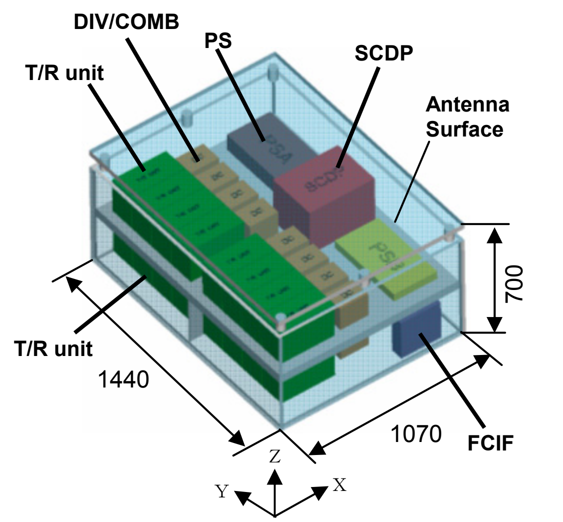

Figure 4b. Internal structure and dimensions of KaPR

degrees, which are also the same as the TRMM PR. Figure 5 shows the antenna scanning method. The KuPR has a swath width of about 245 km, which is executed by ± 17 degrees scan. On the other hand, the KaPR observes a swath width of about 120 km, which is executed by ± 8.5 degrees scan. In the overlapping scan area, measurements will be performed synchronously to match the two beams of KuPR and KaPR. While the KuPR observes the outer swath area, the KaPR can measure snow and light rain in the interlacing scan area in a high-sensitivity mode with a double pulse width, in which the range resolution is 500 m. Another reason for the narrow swath width of KaPR is that the sidelobe clutter contamination in large scan angles will hinder measuring shallow snow clouds. The minimum detectable rainfall rate (0.2 mm/h) of the KaPR is achieved in the case of 500 m range resolution. The observation range is increased to 18 km above sea level (ASL) comparing to the TRMM PR, and mirror image observation will be done near nadir. In all the observing range (-5 to 18 km), over-sampling data (125 m) is

TABLE I. MAIN CHARACTERITICS OF DPR

	KuPR	KaPR
Frequency	13.597 and 13.603 GHz	35.547 and 35.553 GHz
Horinzontal Resolution	5 km (at nadir)	5 km (at nadir)
Swath Width	245 km	120 km
Scan period	0.7 sec	0.35 sec
Range Resolution	250 m	250 m / 500 m
Observation Range	18 km to -5 km ASL	18 km to -3 km ASL
Minimum Detectable Rainfall Rate	0.5 mm/hr (defined by $Z = 200R^{1.6}$)	0.2 mm/hr (defined by $Z = 200R^{1.6}$)
Measurement Accuracy	within ± 1 dB	within ± 1dB
Beam-matching Accuracy	< 1000 m	
Data Rate	< 112 kbps	< 78 kbps
Mass	< 370 kg	< 300 kg
Power Consumption	< 380 W	< 300 W
Size	2.4 × 2.4 × 0.6 m	1.4 × 1.0 × 0.7 m

acquired. In the beam matching antenna scan for the dual-frequency observation i.e., from the 13 to 37th angle-bins shown in Fig.5, it is important to match the position of beams of the two radars. The accuracy of

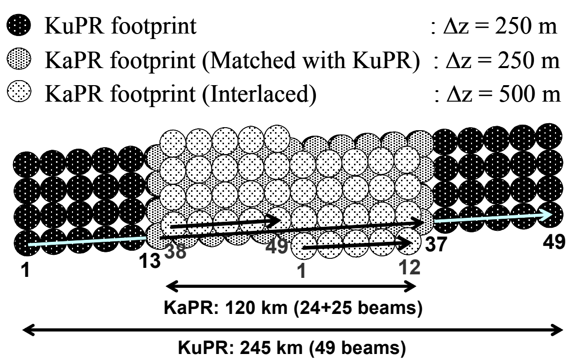

Figure 5. Antenna scanning method of KuPR and KaPR

beam matching is depend on the error sources shown in Table II. The reason which the beam matching error sources other than the ones listed in Table II are not needed to be concerned is because it is possible to fix the errors which do not vary on orbit. Adjustment of the beam positions in the scan direction will be done by adjusting the phase shifters, and to that of the beam positions in the along-track direction will be done by adjusting the pulse transmitting timing. This is possible because the beam matching accuracy is measured by the active radar calibrator (ARC) on ground. In another words, only errors needed to be taken into account are the errors which may vary on orbit. As shown in Table II, based on the spacecraft actual error values and DPR internal error estimation, it is possible to achieve the

TABLE II. BEAM MATCHING ACCURACIES

Error Source Category	Error Source Type	Error (± deg)	
		Scan direction	Along-track direction
Beam matching errors on orbit	Calibration of beam matching accuracy by ARC	0.014	0.014
	Phase tuning accuracy	0.02	N.A.
	Signal synchronization accuracy	N.A.	Negligible
	Mistaking yaw direction error*	Negligible	0.01
Deformation of spacecraft	Thermal deformation	0.022	0.023
	Structural dynamics	0.006	0.002
DPR internal Error	Thermal deformation	0.021	0.064
	Phase error	0.042	N.A.
	Total in each direction	0.058	0.070
	Total error	0.091	
	1000 m beam matching accuracy	0.143	

*ARC can only measure the beam location in scan and along-track direction. If a beam error occurs in yaw direction of the satellite, the ARC detects as scan and along-track direction error.

beam matching accuracy better than 1000 m.

IV. VARIABLE PULSE REPETITION FREQUENCY

To obtain higher sensitivity under the limited resources of the spacecraft some technical developments and trade-off studies are needed. The pulse repetition frequency (PRF) of both KuPR and KaPR will vary according to the satellite altitude variation and to the antenna scan angles [2]. Figure 6 shows a schematic graph of the variable PRF (VPRF) technique. The proper PRF is changed by the distance from satellite to the earth surface. The satellite altitude varies as a function of latitude within a range of about 20 km due to the oblate shape of the earth against the circular orbit in the inclination of 65 degrees. Since the satellite altitude information is obtained by the GPS receiver onboard, the optimized PRF and sampling range can be selected in the VPRF table onboard. The VPRF table is prepared beforehand, and is recorded in the SCDP memory. This variable PRF technique improves the signal to noise ratio because of the larger sampling numbers it offers [3].

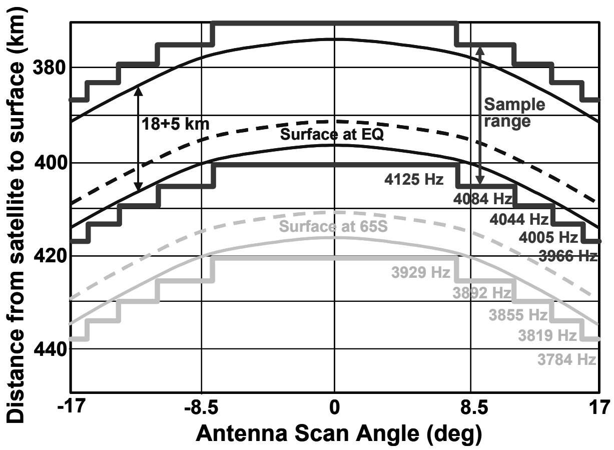

Figure 6. Schematic graph of VPRF as a function of antenna scan angles and satellite altitudes

V. Concluding Remarks

The DPR that will be installed on the GPM core satellite is being developed by JAXA and NICT. The main objective of the DPR is to measure the three-dimensional structure of precipitation including light rainfall and snowfall in high latitudes. For that purpose, it is necessary to improve the sensitivity and accuracy of precipitation measurement compared to the TRMM PR. High sensitivity measurement for light rainfall and snowfall is achieved by taking advantage of KaPR. The VPRF technique is effective to improve the sensitivity. Accurate rainfall estimates will be provided by the difference in rain attenuation information using the matched beam data observed by KuPR and KaPR.

The structural designs of both KuPR and KaPR are similar to the TRMM PR which consists of the 128-element active phased array antenna, SSPA, LNA, PHS, FCIF, SCDP, and other components. To decrease the mass of KuPR and KaPR, the SCDP installed on KuPR is used for controlling both KuPR and KaPR. The other SCDP on KaPR is just for redundancy. Also it is shown that the 1000 m beam matching accuracy can be achieved by the DPR.

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