

## DEVELOPMENT STATUS OF THE DUAL-FREQUENCY PRECIPITATION RADAR FOR THE GLOBAL PRECIPITATION MEASUREMENT

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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. The GPM is a follow-on mission of the Tropical Rainfall Measuring Mission (TRMM). The objectives of the GPM mission are to observe global precipitation more frequently and accurately than TRMM. According to the different detectable dynamic ranges, The KaPR will detect snow and light rain, and the KuPR will detect heavy rain. In an effective dynamic range in both KuPR and KaPR, drop size distribution information and more accurate rainfall estimates will be provided by a dual-frequency algorithm. This paper describes the development status of the DPR.

### 1. INTRODUCTION

The Dual-frequency Precipitation Radar (DPR) on the Global Precipitation Measurement (GPM) core satellite is being developed by Japan Aerospace Exploration Agency (JAXA) and National Institute of Information and Communications Technology (NICT). The GPM is a follow-on mission of the Tropical Rainfall Measuring Mission (TRMM). The objectives of the GPM mission are to observe global precipitation more frequently and accurately than TRMM. The frequent precipitation measurement about every three hours will be achieved by some constellation satellites with microwave radiometers (MWRs) or microwave sounders (MWSs), which will be developed by various countries. The accurate measurement of precipitation in mid-high latitudes will be achieved by the DPR. The GPM core satellite is a joint product of National Aeronautics and Space Administration (NASA), JAXA and NICT. NASA is developing the satellite bus and the GPM microwave radiometer (GMI), and JAXA and NICT are developing the DPR. Figure 1 shows the on-orbit image of the GPM core satellite. JAXA and NICT are developing the DPR through a procurement. The contract for DPR is NEC TOSHIBA Space Systems, Ltd.

### 2. OBJECTIVES

Figure 2 shows the concept of precipitation measurement by the GPM core satellite. The configuration of precipitation measurement using an active radar and a passive radiometer is similar to TRMM. The major difference is that DPR is used in GPM instead of the precipitation radar (PR) in 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 similarly to TRMM. The DPR consists of two radars, which are Ku-band (13.6 GHz) precipitation radar (KuPR) and Ka-band (35.55 GHz) precipitation radar (KaPR).

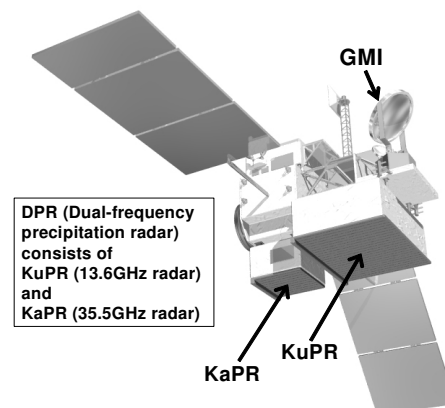


Figure 1. On-orbit Image of GPM Core Satellite

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 estimated precipitation amount by MWRs and MWSs on the constellation satellites.

Figure 3 shows the concept of dual-frequency measurement of precipitation. According to the different detectable dynamic ranges, The KaPR will detect snow and light rain,

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and the KuPR will detect heavy rain. In an effective 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 (Adhikari, N. B, 2003). 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 so on. This database must be useful in improving the MWR and MWS algorithm.

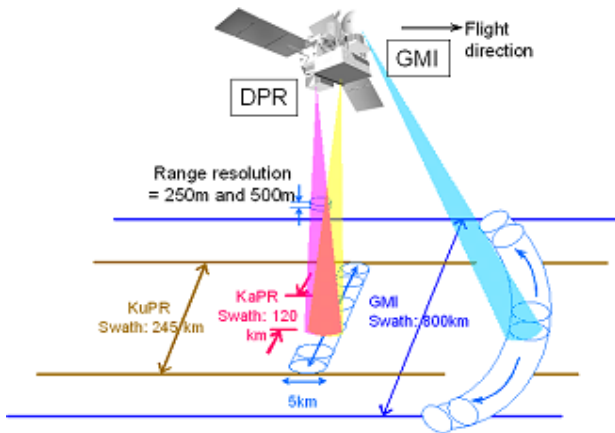


Figure 2. Concept of precipitation measurement with GPM core satellite

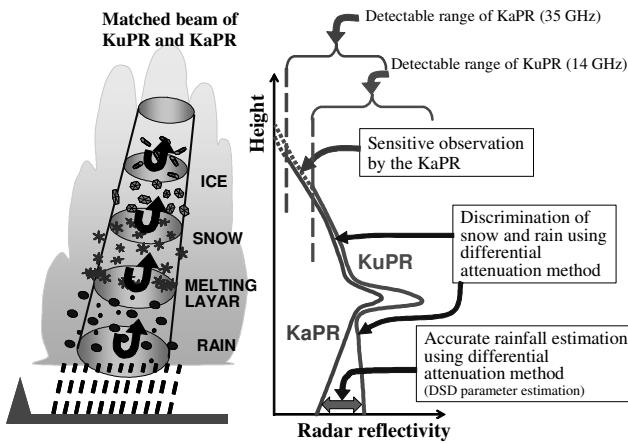


Figure 3. Concept of dual-frequency measurement of precipitation

### 3. TECHNICAL PERFORMANCE AND RESOURCE ALLOCATIONS

The result of the critical design of the DPR satisfied the performance requirements which includes functions of radar pulse transmitting and radar echo receiving, beam scanning, received echo averaging, internal calibration, system noise measurement, operation analysis, beam matching, variable pulse repetition frequency, thermal control, command and

data handling, power supply, contingency observation, re-programming of onboard software and parameter change by command and so on.

Table 1 shows the general design specifications of the DPR. For each radar, two frequencies are used to double the sampling number (two frequency agility). Figure 5 shows the antenna scanning method of KuPR and KaPR. The range resolution of the matched beams is 250 m for KuPR and KaPR, which means a transmitting pulse width is 1.6  $\mu$ s. When the KuPR observes the outer swath area, the KaPR can measure snow and light rain in the interlacing scan area in the high-sensitivity mode with a double transmitting pulse width (3.2  $\mu$ s), in which the range resolution is 500 m. The beam width of both KuPR and KaPR is 0.7 degrees, and the horizontal resolution is 5 km when the spacecraft altitude is 407 km. The KuPR has a swath width of about 245 km, which is executed by  $\pm 17$  degrees scan. On the other hand, the KaPR observes a swath width of about 120 km, which is executed by  $\pm 8.5$  degrees scan. In the overlapping scan area, measurements will be performed synchronously to match the two beams of KuPR and KaPR.

	KuPR	KaPR
Frequency	13.597 & 13.603 GHz	35.547 & 35.553 GHz
Range Resolution	250 m	250 m / 500 m
Spatial Resolution	5 km (at nadir)	5 km (at nadir)
Swath Width	245 km	120 km
Minimum Detectable Rainfall Rate	0.5 mm/hr	0.2 mm/hr
Beam-matching Accuracy	< 1000 m	
Observable Range	Up to 19 km	Up to 19 km
Dynamic Range	- 5 dB below system noise level + 5 dB over surface echo level	- 5 dB below system noise level + 5 dB over surface echo level
Received Power Accuracy	Within $\pm 1$ dB	Within $\pm 1$ dB
Data Rate	< 109kbps	< 81 kbps
Power Consumption	< 446 W	< 344 W
Mass	< 472 kg	< 336kg
Size	2.5 $\times$ 2.4 $\times$ 0.6 m	1.4 $\times$ 1.2 $\times$ 0.8 m

Table 1. General design specifications

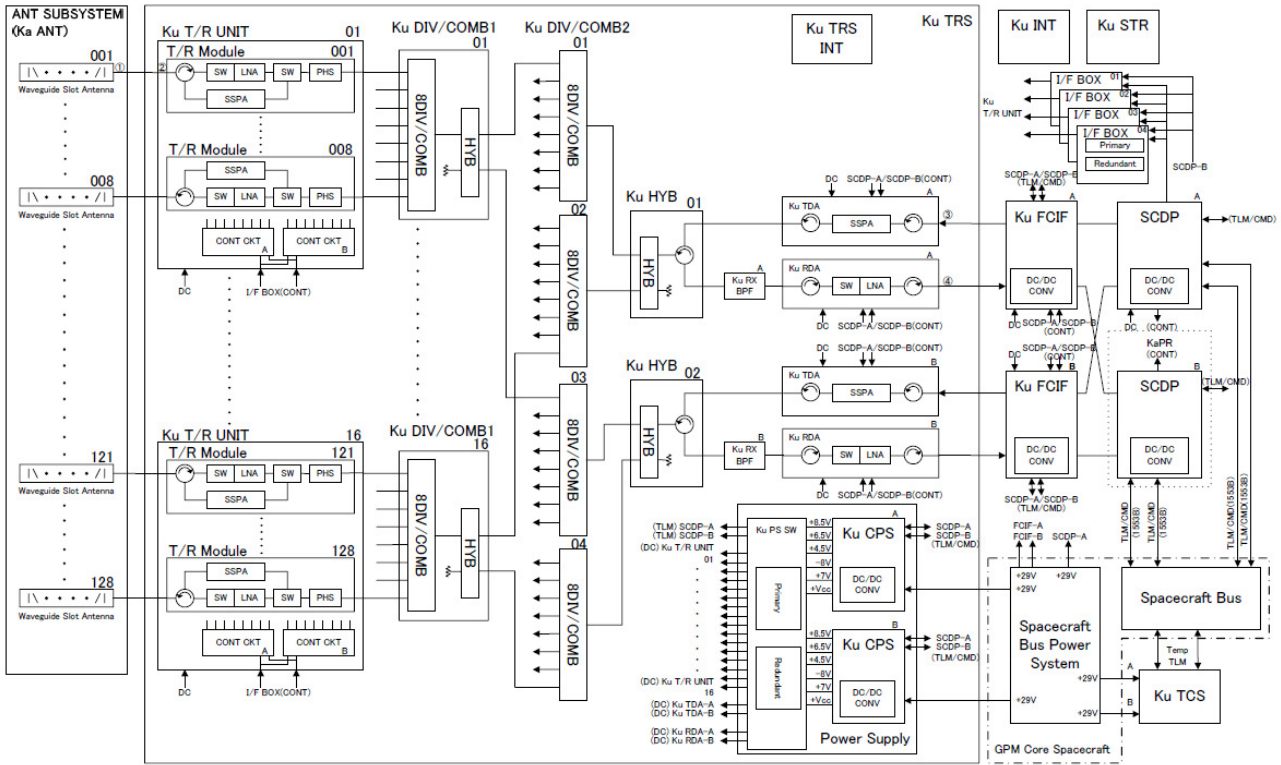


Figure 4. Block diagram of KuPR

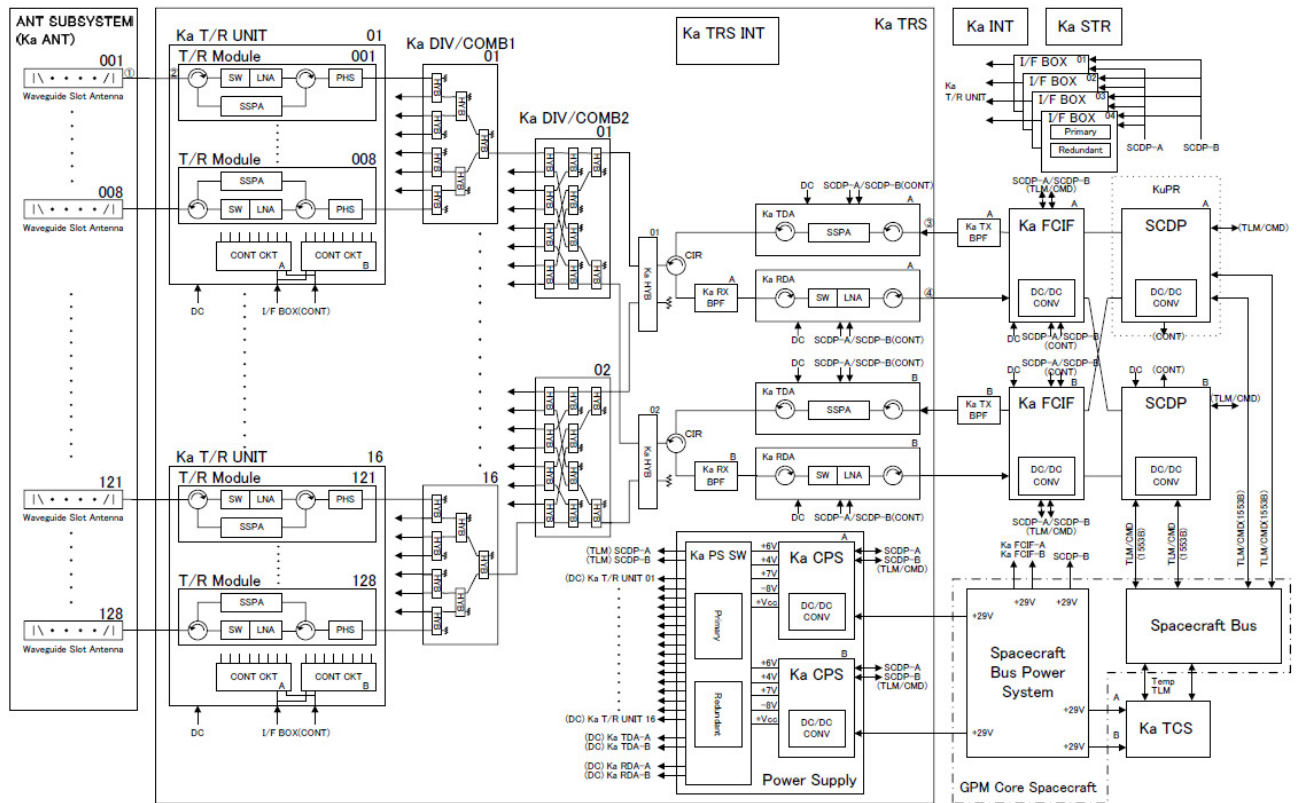


Figure 5. Block diagram of KaPR

Another reason for the narrow band 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 resolution. To obtain higher sensitivity, DPR adopted variable pulse repetition frequency (VPRF) technique (Kobayashi, S. 2003 and Senbokuya Y. 2004). In the beam matching antenna scan for the dual-frequency observation i.e., from the 13 to 37th angle-bins for KuPR and from the 1 to 25th angle-bins for KaPR is shown in Fig.5. The requirement of the beam-matching accuracy is to match the position of beams of the two radars within 1000 m. The accuracy of mechanical beam matching is depend on the alignment of the satellite bus, however it is possible to adjust the beam positions in the scan direction by adjusting the phase shifters and in the along-track direction by adjusting the pulse transmitting timing in the orbit because the beam matching accuracy is measured by the active radar calibrator (ARC) on the ground. The observation range is increased to 19 km ALS comparing to the TRMM PR, and mirror image observation will be done near nadir.

**4. SYSTEM DESCRIPTION**

Figure 4 and 5 show the block diagrams of KuPR and KaPR. They show how the signals go through each component. Both KuPR and KaPR have almost the same design as the TRMM PR. Each radar has 128 slot array antennas, transmitters (Solid State Power Amplifier: SSPA), receivers (Low Noise Amplifier: LNA), Phase Shifters (PHS), and so on. Frequency Converter Intermediate Frequency (FCIF) and System Control Data Processing (SCDP) of both KuPR and KaPR have almost the same designs. To make the structures lighter, one SCDP installed on KuPR is used to control both KuPR and KaPR. The other SCDP which is installed on KaPR, is just for redundancy. There are two major differences from TRMM/PR. One major difference is that T/R module groups one SSPA, LNA, and PHS together, and one T/R unit consists of 8 T/R modules. In each radar, there are 16 T/R units. Another one is the design change of Divider/Combiner (DIV/COMB), Circulator (CIR) and Hybrid (HYB) to eliminate the single failure point in RF line. The analysis results using subsystems and components design and parameters reviewed in the critical design of the DPR have achieved the required technical performance of frequency, range resolution, spatial resolution, swath width, minimum detectable rainfall rate, beam matching accuracy, observable range, dynamic range, received power accuracy, and so on.

- KuPR footprint :  $\Delta z = 250$  m
- ⊕ KaPR footprint (Matched with KuPR) :  $\Delta z = 250$  m
- KaPR footprint (Interlaced) :  $\Delta z = 500$  m

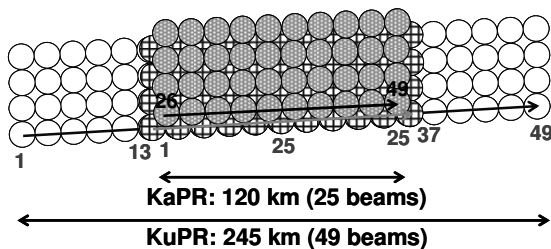


Figure 6. Antenna scanning method of KuPR and KaPR

**5. DEVELOPMENT AND MANUFACTURING**

In order to verify designs of proto-flight model and manufacturing processes, all kinds of component for DPR are developed with engineering models (EM). KuPR engineering model (KuPR EM) and KaPR engineering model (KaPR EM) are composed of the component engineering models.

Meachanical design and thermal design of KuPR and KaPR are verified with structure models (STM)

The development test items are summarized in Table 2. Through the development test, new designs are satisfies requirements and are confirmed the readiness to manufacture proto-flight model. Currently, components of proto-flight model has been manufactured.

Table 2. Development test items

	Test items
Component EM	electrical function test / vibration test / shock test thermal vacuum test (or thermal cycle test) electromagnetic compatibility test mechanical inspection
KuPR EM KaPR EM	electrical function test (including RF characteristics) thermal vacuum test electromagnetic compatibility test mechanical inspection compatibility test with spacecraft simulator
KuPR STM KaPR STM	alignment test / mass properties test sinusoidal vibration test / modal survey test acoustic test / thermal balance test mechanical inspection
DPR	co-operation test

**6. 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, the allocated requirements of each component and the performance of DPR system are verified through the development test. The results of critical design of the DPR instrument satisfied these requirements as a spaceborne radar. The DPR system has currently been manufactured.

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