Radio Frequency Sensor Technology for Global Rain and Cloud Observation

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Abstract

The Dual-frequency Precipitation Radar (DPR) installed in the Global Precipitation Measurement (GPM) core satellite is the successor to the Tropical Rainfall Measuring Mission/Precipitation Radar (TRMM/PR) that was launched in 1997 and is still in use. It observes global precipitation distribution, including high-latitude regions, using two radars in the Ku and Ka bands. Meanwhile, the Cloud Profiling Radar (CPR) installed in the EarthCARE satellite observes the clouds of entire globe with approximately 10 times greater sensitivity than that of existing satellite-borne cloud radars. The CPR is the first satellite-borne millimeter-wave radar in the world with a Doppler velocity measuring function. These technologies will be applied to radars installed in earth observation and security-related satellites in the future.

Keywords

satellite, earth observation, rainfall radar, precipitation radar, phased array antenna, cloud radar doppler radar, CFRP core, germanium coating

1. Introduction

Climate changes at the global scale, such as global warming, have been attracting attention recently. Factors affecting climate change include the distribution of rainfall and clouds, and the only means of knowing their global distribution on both land and ocean areas is through observation using satellites. NEC and Toshiba Corporation were jointly in charge of the development of the Tropical Rainfall Measuring Mission/Precipitation Radar (TRMM/PR) installed on the TRMM satellite launched in November 1997. It was the world's first satellite-borne rainfall radar.

The TRMM/PR is highly acclaimed and is still working 13 years after its launch, substantially exceeding its design life of 3 years. Currently, as the missions succeeding the TRMM, NEC and NEC TOSHIBA Space Systems, Ltd. (hereinafter referred to as “we”) are designing and manufacturing the Global Precipitation Measurement/Dual-frequency Precipitation Radar (GPM/DPR) to be installed in the GPM core satellite, which is under Japan-US joint development, and the Earth Clouds, Aerosols and Radiation Explorer/Cloud Profiling Radar (EarthCARE/CPR) to be installed on the EarthCARE satellite, which is an earth observation satellite under Japan-EU joint development. In this paper, we will introduce the precipitation and cloud observation radars to be used with these satellites. In addition, we are also developing another radar, a Synthetic Aperture Radar (SAR). The SAR is introduced in a separate paper in the present feature pages, entitled “Small SAR Satellite Technology Promotes Dissemination of a Comprehensive Space Utilization System”.

2. Dual-frequency Precipitation Radar (DPR)

The TRMM/PR transmits a Ku-band radio wave from the satellite to the Earth and receives the radio waves scattered by raindrops. The GPM/DPR is designed to be capable of observing a wide range of precipitation by combining a Ka-band Precipitation Radar (KaPR) suitable for observing weak rainfall and a Ku-band Precipitation Radar (KuPR) suitable for observing strong rainfall. The KuPR has been improved in performance over that of the TRMM/PR, including an increase in transmission power.

The DPR is being developed in cooperation with the Japan Aerospace Exploration Agency (JAXA) and the National Institute of Information and Communications Technology (NICT). It will be carried on the GPM core satellite (**Fig. 1**) developed by NASA and will be launched by JAXA's H-IIA launch vehicle in FY2013.

We are in charge of the design and manufacture of the DPR according to an contract with JAXA. We have already

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Fig. 1 External view of the GPM core satellite.

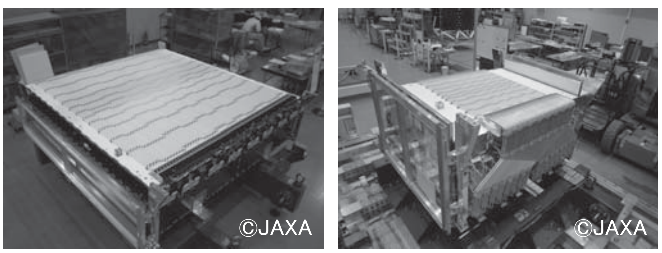

Photo 1 External views of KuPR (Left) and KaPR (Right). (The upper sections are the antenna subsystem. OSR protection covers are attached on the side panels.)

completed manufacture of the proto-flight model (PFM) and are currently under test.

2.1 Outline of the DPR

(1) External view and configuration

The KuPR and KaPR have box-shaped structures (**Photo 1**) and their sizes are, respectively, 2.6 m × 2.4 m × 0.7 m (KuPR) and 1.3 m × 1.5 m × 0.8 m (KaPR).

Each structure incorporates a Transmission/Reception subsystem (TRS), a Frequency Converter/Intermediate Frequency unit (FCIF) and a System Control/Data Processor (SCDP), and an antenna subsystem (ANT) is installed on the nadir side of the structure. On the sides of each structure, optical solar reflectors (OSRs) for heat dissipation are attached, and the other outer surfaces, except the antenna, are covered mainly with germanium-deposited heat control film.

(2) Main functions and specifications

The DPR emits a radio wave by variable pulse repetition frequency (PRF) according to satellite altitude and measures the intensity of the signals scattered by raindrops (echo signals). The function of variable PRF according to satellite altitude is newly added with the TRMM/PR.

The signals scattered by raindrops are converted into the intermediate frequency band and are then subjected to logarithmic detection. The output video signal is then A/D converted, subjected to digital signal processing such as integration and sent as observation data to the ground through the core satellite.

The main functions and specifications of the KuPR and KaPR are as follows:

- Observed rainfall strength:
  KuPR ≧ 0.5 mm/h, KaPR ≧ 0.2 mm/h
- Observed altitude range:Ground surface to 19 km
- Observation scanning width:
  KuPR 245 km, KaPR 125 km
- Variable PRF according to altitude information from the satellite
- Internal/external calibration function
- Independent thermal control from the satellite

2.2 Technologies Implementing the DPR's Functions and Specifications

The KuPR and KaPR can identify the altitude distribution of precipitation based on the time from the transmission of the radio wave until the reception of echoes from raindrops. And, they have a function for scanning an antenna beam in the cross-track direction. So, they can measure 3D precipitation distribution. Both the KuPR and KaPR adopt a phased array antenna to achieve this antenna beam scanning. The antenna subsystem is composed of 128 antenna elements, and the antenna beam is scanned electronically by controlling the phase of the radio wave transmitted or received by each antenna element. For this purpose, each antenna element has a T/R module incorporating a phase shifter, a solid state power amplifier (SSPA) for amplifying the transmitted radio wave, and a low-noise amplifier (LNA) for amplifying the transmitted radio wave. To save installation space, every eight T/R modules are grouped into a T/R unit (**Photo 2**).

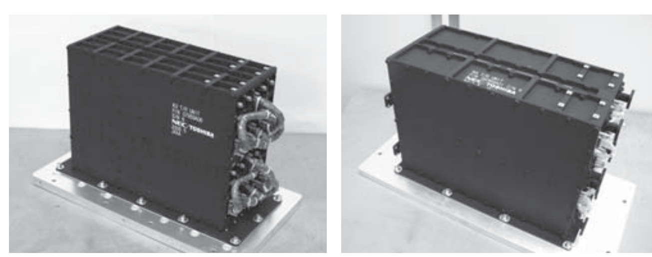

Photo 2 Ku T/R unit (Left) and Ka T/R unit (Right).

The SSPAs and LNAs incorporated into the T/R unit are equipped with high-precision temperature compensation so that they can collect data stably without causing gain variation, even when exposed to the severe temperature environments of outer space.

3. Cloud Profiling Radar (CPR)

The EarthCARE (**Fig. 2**) is a satellite for global-scale observation of the vertical distribution of cloud particles and aerosols (fine particles in the atmosphere, such as dirt and dust) and the velocity of the upward/downward movement of cloud particles. The results of these measurements will be applied to elucidate the heating/cooling effect of clouds and aerosols and to improve the accuracy of climate change prediction.

The CPR is a radar that transmits a millimeter- band radio wave from the satellite orbit to the Earth and receives the radio waves scattered by cloud particles. It is capable to observe clouds with approximately 10 times greater sensitivity than the existing satellite-borne cloud radars. The CPR is the first satellite-borne millimeter-wave radar in the world with a Doppler velocity measuring function, which can detect the vertical distribution of clouds as well as the velocity of the upward/downward movement of clouds.

The EarthCARE is under joint development by JAXA and the European Space Agency (ESA). The CPR is being developed by JAXA and NICT, and we are in charge of its design and manufacture according to a contract with JAXA. We have already manufactured the ground test model and are conducting development test.

3.1 Outline of the CPR

(1) External View and Configuration

The CPR is composed of a main reflector (MREF), deployment mechanisms (DPM), hold/release mechanisms (HRM), a support structure (STR), a quasi-optical feed system (QOF) and a platform (**Fig. 3**).

The platform incorporates a transmitter/receiver subsystem (TRS), signal processor units (SPU) and a heater switch (HSW). Part of the outer surface of the platform is covered with optical solar reflectors (OSRs) for heat dissipation, and other outer surfaces are covered mainly with germanium-coated thermal control film. The MREF is stowed at the time of launch and deployed in orbit. The QOF and TRS are being developed by NICT and JAXA.

(2) Main functions and specifications

The CPR emits a 94-GHz-band radio wave while varying pulse repetition frequency (PRF) according to satellite altitude and measures the intensity and phase profile of the signals scattered by cloud particles (echo signals).

The signals scattered by clouds are converted into the intermediate frequency band and then their intensity is subjected to logarithmic detection while the phase is subjected to IQ detection. The output is then A/D converted, subjected to digital signal processing such as integration, and sent as observation data to the ground through the satellite body.

The main functions and specifications of the CPR are as follows:

- Minimum detection sensitivity: ≦ 35 dBZ (at top of atmosphere)
- Doppler velocity precision: ≦ 1.0 m/s
- Internal/external calibration of satellite-borne equipment
- MREF deployment/holding functions and thermal control function

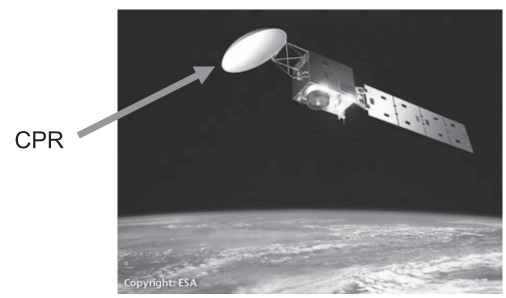

Fig. 2 External view of EarthCARE.

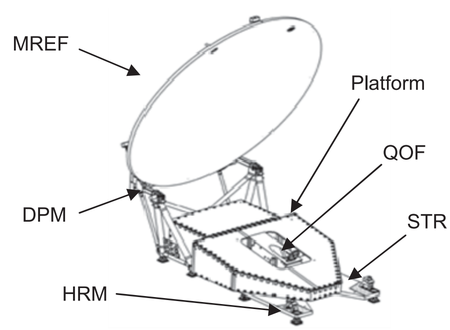

Fig. 3 External view and configuration of the CPR (With MREF deployed, excluding thermal control parts).

3.2 Technologies Implementing Functions and Performance

(1) System and signal processor block
The diameter of the CPR observation range is about 700 meters. Since the satellite moves at an ultrahigh ground speed of about 7 km per second, the observation range is passed in only 0.1 seconds. To measure the vertical velocity of cloud particles with the specified precision in such a high-speed situation, system design is conducted by checking with detailed Doppler velocity simulations. A/D conversion with a resolution equivalent to 16 bits is required to implement the Doppler velocity precision; however, we achieve the required resolution by combining an A/D converter with 14-bit resolution with oversampling signal processing technology since there is no satellite-use A/D converter with a resolution higher than 15 bits available. .

(2) High-surface-accuracy MREF
To implement high-sensitivity observation and Doppler velocity measurement, an MREF with an aperture diameter of 2.5 meters (**Photo 3** Left) of the CPR is required to have higher mirror surface accuracy than conventional communications antennas (i.e., less than 60 μm RMS). It must meet this high-surface-accuracy requirement under the severe restrictions imposed by the wide temperature variations in orbit (approx. -50 to +60°C) and the weight limit. We therefore apply a sandwich structure in which high-elasticity carbon-fiber reinforced plastic (CFRP) face sheets are adhered on both sides of a newly developed CFRP flex honeycomb core (Photo 3 Right). This core makes it possible to reduce the thermal expansion/contraction of the MREF in both the in-plane and out-of-plane directions, thereby greatly reducing the deformation of the MREF during manufacture as well as in orbit.

(3) Sunlight concentration prevention
The CPR points at the Earth during regular operation; however, the CPR may point at the Sun due to satellite attitude error, causing sunlight to concentrate on the QOF located near the focal point of the MREF and that leads a rapid temperature rise within a short time of period. To inhibit such concentration, the reflecting surface of the MREF is covered with germanium-coated film to absorb and diffuse the sunlight (**Photo 4**). Entire aperture diameter of 2.5 meters is covered by connecting several segments of extremely thin film (approximately 25 μm in thickness) to minimize effects on 94-GHz-band radio waves.


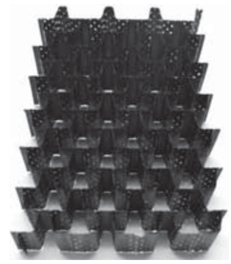

Photo 3 Main reflector (Left) and CFRP flex honeycomb core (Right).

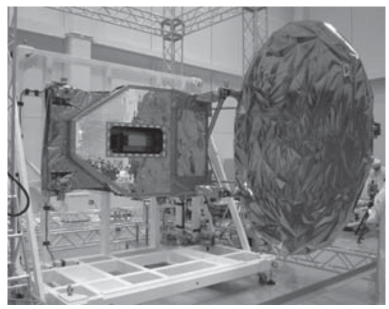

Photo 4 Reflecting surface of main reflector covered with germanium-coated film.

4. Conclusion

Since the TRMM/PR was launched as the world's first satellite-borne precipitation radar, we have been developing the GPM/DPR to follow it up, aiming at further improvement of observation performance. We are also improving our technical ability in radar system and signal processing design technology, high-surface-accuracy reflector design and manufacturing technology, sunlight concentration prevention technology, etc. through the design and manufacture of the CPR, equipped with the world's first Doppler velocity measurement function. In the future, we will effectively apply these technologies to the radars installed in earth observation and security-related satellites, as well as to the high-gain, high-pointing accuracy antennas installed in general satellites.

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