IMPROVEMENT IN THE SENSITIVITY OF SPACEBORNE PRECIPITATION RADAR FROM TRMM TO GPM

Shinsuke SATOH *, Nobuhiro TAKAHASHI, Toshio IGUCHI
National Institute of Information and Communications Technology (NICT), Koganei, Japan

Shuji SHIMIZU, Kinji FURUKAWA, Masahiro KOJIMA
Japan Aerospace Exploration Agency (JAXA), Tsukuba, Japan

Minoru OKUMURA
NEC TOSHIBA Space Systems, Ltd., Yokohama, Japan

1. INTRODUCTION

The sensitivity of spaceborne precipitation radar is an important factor for meteorological and climatological studies. The TRMM precipitation radar (PR) is a superior instrument to measure precipitation over both sea and land, and its data have been used for many research fields. However, the PR has a limitation of the sensitivity because the PR measures rainfall from a large distance of about 400 km and the performance of spaceborne radar is restricted by the limited resources (power, mass, size) of spacecraft. On the other hand, the dual-frequency precipitation radar (DPR) on the Global Precipitation Measurement (GPM) core satellite is being developed as a follow-on instrument of the TRMM PR (Satoh et al, 2004). Since the GPM core satellite also observes precipitation at high latitudes (between 65°S and 65°N), it is important that the DPR has higher sensitivity to measure light rainfall and snowfall. The objectives of this study are to make clear the minimum detectable rainfall rate of the spaceborne radars on TRMM and GPM, and to show how to improve the sensitivity of the GPM DPR.

2. DEFINITION OF MINIMUM DETECTABLE RAINFALL RATE

The DPR consists of Ku-band (13.6 GHz) precipitation radar (KuPR) and Ka-band (35.5 GHz) precipitation radar (KaPR). The KaPR has two kinds of pulse transmitting width; one is 1.6 μs for 250 m range resolution same as KuPR and the other is 3.2 μs for 500 m range resolution. The minimum detectable rainfall rate in the specifications is prescribed as follows; 0.5 mm/hr in 250 m range resolution for KuPR and KaPR, 0.2 mm/hr in 500 m resolution for KaPR. The minimum detectable rainfall rate is defined by (1) ignoring the rain attenuation, at the earth ellipsoid surface level when the regulation satellite altitude is maximum, (2) considering the judgment on the presence of rain using 2-σ threshold in a signal distribution for no-rain, (3) the signal power in terms of Z-factor corresponding to the 2-σ threshold is translated into the minimum rainfall rate using a general Z-R relationship ($Z=200R^{1.6}$) for weak rainfall.

In general, the radar signal power is measured as [signal power]=[total receiving power]–[noise power], where total receiving power and noise power are independently measured by a logarithmic detector. When an enough number of sampling is used for averaging, the standard deviation of total receiving power (σt) with fading and the standard deviation of noise power (σn) with fading are expressed by

σt = 5.57/SQRT(*N*) = 0.568 dB (*N*=96)

σn = 5.57/SQRT(*M*) = 0.208 dB (*M*=720)

where *N* and *M* are sampling numbers for total receiving power and noise power, respectively. The origin of these equations is shown by Kumagai et al (1996). In the next step, using a minimum noise power of 16.4 dBZ detected by one pulse (S/N=1, Te=323K (50C), Ta=290 K (17C), Emissivity=0.95) of KaPR in 500 m range resolution, the expected total receiving power considering the 2-σ threshold is expressed by

16.4 + 2×SQRT($\sigma t^2+\sigma n^2$) = 17.61 dBZ.

The signal power is calculated by

10^1.761 – 10^1.64 = 14.0 (real) → 11.5 dBZ.

The result of 11.5 dBZ corresponds to 0.2 mm/hr using the above-mentioned Z-R relationship.

* *Corrsponding author address: Shinsuke Satoh, NICT, Precipitation Radar Group,
4-2-1, Nukui-kitamachi, Koganei, Tokyo 184-8795 Japan; e-mail: satoh@nict.go.jp*

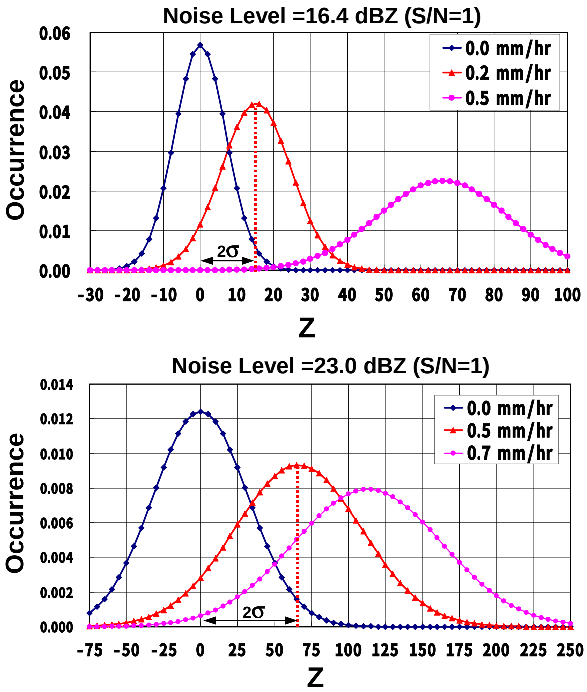

Fig. 1: Probability distributions of signal power for 0.2 mm/hr (top) and 0.5 mm/hr (bottom) with reference signal distributions for different rainfall rates. The horizontal axis shows Z-factor.

Figure 1 shows the probability distribution of the signal power for corresponding to 0.2 mm/hr when the minimum noise power of 16.4 dBZ as mentioned the above. Also, it shows another signal power distribution for 0.5 mm/hr when the minimum noise power of 23.0 dBZ for 250 m range resolution of KuPR and KaPR. Each distribution is a normal distribution, and the 2-σ threshold leads that the probability of the judgment on the presence of rain in a signal distribution for no-rain is 5%

3. VARIATIONS IN SYSTEM NOISE

The system noise level is determined by the thermal noise of the receiver and the background noise from the radiation of the earth surface, precipitation, water vapor, etc. Figure 2 shows the long-term variation of the thermal noise level of TRMM PR. The system noise data is averaged by a round of no-rain data to reduce the fading effect. The solar beta angle is defined as an angle between the satellite orbit plane and the direction from the earth to the sun. Since the sunlight is applied to the top of the TRMM satellite when the solar beta angle is zero, the PR installed on the bottom of

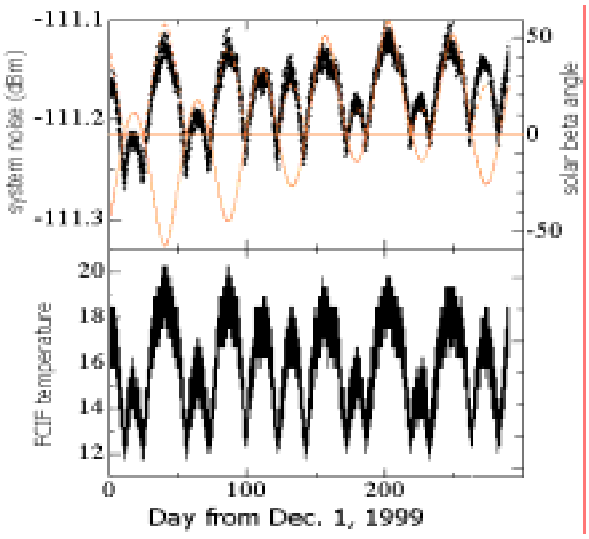

Fig. 2: Long-term change of the system noise and the solar beta angle (top), and the FCIF temperature (bottom)

the satellite is not warmed. Figure 2 shows the variation of the system noise corresponds with the solar beta angle and the FCIF temperature. The amplitude of the variation is less than 0.15 dB, and is very stable for the long-term period. In addition to this, Takahashi and Iguchi (20004) reported that the background noise level over ocean is related with the sea surface temperature, and the amplitude of the variation is less than 0.1 dB. Over land, the mean noise level is about 1 dB larger than it over sea because of the large emissivity, and the variation is also larger a little than over sea. In a case of rain, the background noise increases according to the rainfall rate or vertical accumulated rainfall, because of the emission from rain. However, the mean amplitude of the increasing noise level is less than about 0.5 dB. Although the system noise level varies according to such reasons, the amplitude of the variation is less than the fading variation of about ±1 dB shown in Fig. 3

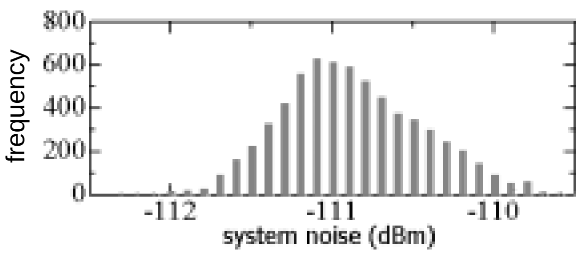

Fig. 3: An example of the system noise distribution

4. IMPROVEMENT IN SENSITIVITY

4.1 Noise Sampling Window for TRMM PR

In TRMM PR, the system noise is sampled in the noise-sampling window shown in Fig. 4. In order to avoid the rain echoes, surface echoes, and sidelobe culler echoes, the noise-sampling window is located at the near side of the rain echo in scan edge sides, and at the far side of the surface echo around the nadir. However, because the receiver (LNA) gain, which is related to the temperature, changes with time (range bin offset) caused by the T/R switching, the noise data in each angle bin is also need to correct the offset shown in Fig. 5.

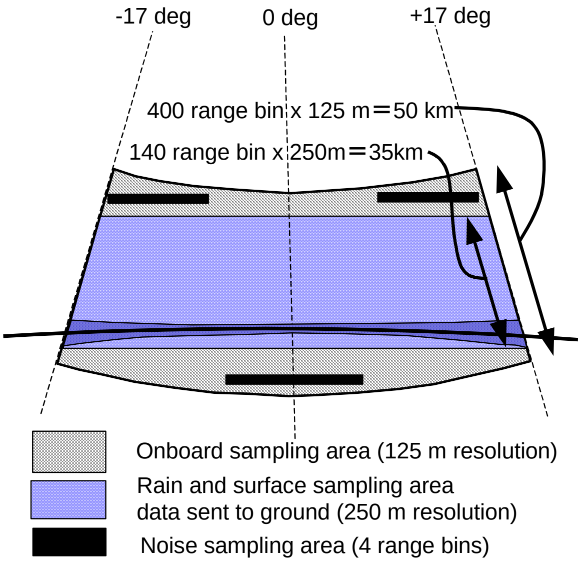

Fig. 4: Noise sampling window for TRMM PR

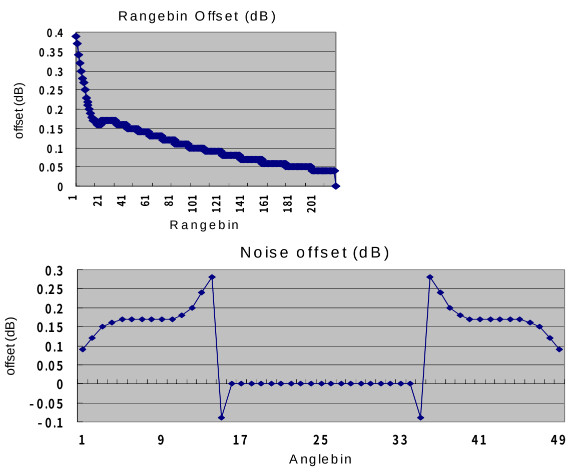

Fig. 5: Range bin offset and noise offset in 1B21.

4.2 Variable PRF for GPM DPR

In GPM DPR, the pulse repetition frequency (PRF) of both KaPR and KuPR varies according to the satellite altitude variation and to the antenna scan angles (Kobayashi and Iguchi, 2003). While the proper PRF is changed by the distance from satellite to the earth surface, the variation of the GPM core satellite altitude is lager than TRMM because of the large inclination angle (65 deg). For that reason, the variable PRF (VPRF) technique is necessary to keep the enough sampling number. Since the satellite altitude information is obtained by the GPS receiver on board, the optimized PRF and sampling range can be selected in the VPRF table on board. Figure 6 shows the sampling window according to the variable PRF technique. There is no extra area to sample the system noise like TRMM PR. Since the noise-sampling window for TRMM PR has a problem of correcting the range bin offset, another noise sampling technique is adopted for GPM DPR to obtain more reliable system noise data.

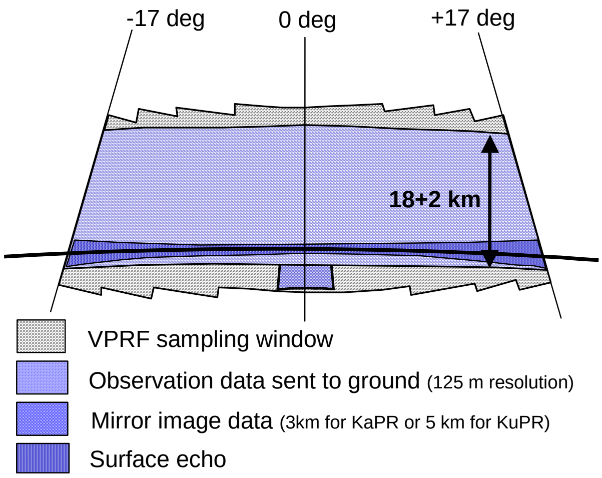

Fig. 6: Sampling window for GPM DPR

The system noise data sampled during the transmitting tern-off period of the last five pulses in the averaging pulses in a beam. The sampled noise data is averaged in the range direction on board, the four noise data corresponding to the last four pulses are sent to ground. As the results of the VPRF technique and the Tx-off noise sampling technique, the sampling number of the total receiving power (N) is more than 96, the noise sampling number (M) is 720 (4 pulses × 80 range bins × 2 freq agility) as mentioned in section 2. The standard deviation of signal power must be 0.60 dB (=SQRT(0.568^2 +0.208^2)), which is improved comparing with the TRMM PR case of 0.78 dB (N = 64, M = 256).

5. VARIATION IN SATELLITE ALTITUDE

The satellite altitude varies as a function of latitude within a range of about 18 km due to the oblate shape of the earth against the circular orbit in the inclination of 65 degrees as shown in Fig. 7. Since this figure shows a result of the approximate calculation, the actual variation including atmospheric drag etc will increase about ±1 km.

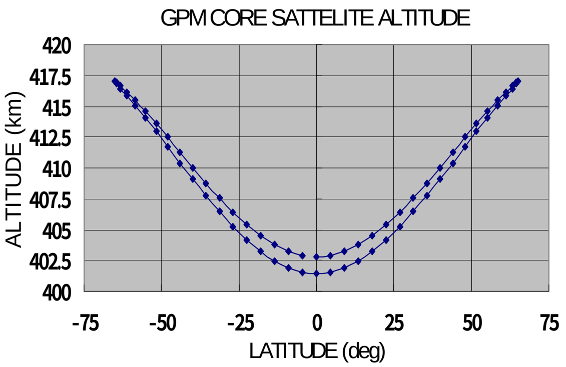

Fig.7: Variation in the altitude of GPM core satellite

Since the propagation loss (Lp) is expressed by

Lp = -20×LOG(4 × π × R) [dB] ,

R=401 km: Lp = -134.047 (0.381 dB)

R=419 km: Lp = -134.428 (0 dB).

Therefore, the sensitivity over the equator has an advantage of 0.4 dB comparing with high latitudes.

6. SUMMARY

Some issues of the sensitivity improvement of spaceborne radar are described. It is not so easy to improve the sensitivity under the restricted resources (power, mass, size) of spacecraft and the severe conditions (satellite altitude, temperature). The effort toward improving the transmitting power had been continued for several years, it is difficult to improve more the performance of the device of the solid transmitter. In this study, the definition of the minimum detectable rainfall rate and the importance of the system noise are described. Although the mean system noise level in TRMM PR is stable for long term, the noise sampling method has to be changed in GPM DPR to adopt the VPRF technique. According to increase the sample number of the total receiving signal and the system noise using the VPRF, the standard deviation of the signal power with fading decreases into 0.6 dB. This is very effective to improve the sensitivity.

Although the 0.2 mm/hr for KaPR in 500 m range resolution are determined in worst conditions (temperature, over land, 419 km in satellite altitude) in the hardware specifications, the practical sensitivity may be higher because of the actual mitigating conditions. Over ocean, the mean noise level is about 1 dB less than over land. Over the tropics, the propagation loss is smaller about 0.4 dB than the maximum satellite altitude in high-latitudes. Although this study did not treat the matters of the Drop size distribution (Z-R relation) and the Mie-scattering effect, they are also important to discuss the practical sensitivity.

< REFERENCES >

Kobayashi, S., and T. Iguchi, 2003: Variable Pulse Repetition Frequency for the Global Precipitation Measurement Project (GPM). *IEEE Transaction on Geoscience and Remote Sensing*, Vol. 41, No.7, pp.1714-1718.

Kumagai, H., T. Kozu, and T. Iguchi, 1996: Development of an algorithm for rain/no-rain discrimination. Review of CRL, Vol. 42, No. 3, pp.317-323. (in Japanese with English abstract)

Satoh, S., K. Furukawa, Y. Senbokuya, M. Kojima, R. Oki, S. Shimizu, N. Takahashi, H. Hanado, T. Iguchi, M. Okumura, and K. Nakamura, 2004: Development of Spaceborne Dual-Frequency Precipitation Radar for the Global Precipitation Measurment. *24th International Symposium on Space Technology and Science, Miyazaki,* ISTS 2004-n-06.

Takahashi, N., and T. Iguchi, 2004: The characteristics of system noise of TRMM/PR and their application to the rain detection algorithm. *IGARSS 2004, Anchorage*.