Cloud Profiling Radar for the CloudSat Mission

Eastwood Im, Chialin Wu, Stephen L. Durden

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109

1. INTRODUCTION

The CloudSat Mission [1] is a new satellite mission jointly developed by NASA, JPL, the Canadian Space Agency, Colorado State University, and the US AirForce to acquire a global data set of vertical cloud structure and its variability. Such data set is expected to provide crucial input to the studies of cloud physics, radiation budget, water distribution in the atmosphere, and to the numerical weather prediction models. The CloudSat Mission is scheduled for launch in April 2005. The primary science instrument aboard the CloudSat satellite is the Cloud Profiling Radar (CPR). CPR is a 94-GHz nadir-looking radar that measures the power backscattered by clouds as a function of distance from the radar. These data will provide an along-track vertical profile of cloud structure. In this paper, we will present an overview of the CPR instrument.

2. CPR INSTRUMENT DESIGN

The CPR instrument in the CloudSat satellite is graphically depicted in Figure 1. The primary science objective for CPR is to achieve a minimum detectable cloud reflectivity (Z) of -28 dBZ at the end of the mission. This performance is needed since clouds are weak scatterers. Maximizing the cloud detection sensitivity requires careful tradeoff among several competing and often conflicting parameters, including the cloud backscattering sensitivity, atmospheric absorption, resolution, and radar technology. The detection sensitivity is primarily determined by the radar. received power and the noise level. The radar received power can be written as [2]:

$$P_a(r) = \frac{P_t \lambda^2 G^2 \theta^2 \Delta \eta L}{512 \pi^2 \ln 2 r_a^2}$$

where P_t is the transmitter power, λ is the wavelength, G is the antenna gain, θ is the antenna half-power beamwidth, Δ is range resolution, r_a is the range to the atmospheric target, η is the cloud reflectivity[1], and L is the signal loss. $P_a(r)$ is the received power from the atmosphere versus range. The product $G^2 \lambda^2 \theta^2$ is proportional to the antenna effective area. Thus, the received power is increased by increasing antenna area, range resolution, transmit power, and reflectivity. The antenna size is limited by the physical launch constraints such as volume and mass. Transmitted power is limited by the technology of the transmitter itself and by the power supply capability of the spacecraft.

The amount of power received is strongly influenced by the cloud reflectivity and the atmospheric absorption. In general, the cloud reflectivity increases with radar frequency. On the other hand, signal absorption due to atmospheric gases increases with higher frequencies. 94 GHz is indeed a good compromise which provides an increase of 33 dB as compared with, say, the use of the TRMM precipitation radar frequency of 14 GHz, and thus, allows the sensitivity requirement to be met using available technology. Sensitivity is also related to the pulse length *(τ)*. CPR will operate using 3.3-μs monochromatic pulses to provide the required sensitivity while meeting the range resolution requirement of 500 m. The other approaches for improving sensitivity involve reducing noise from various sources. The receiver noise is minimized by using a low noise amplifier and by reducing the losses between the antenna and the low noise amplifier. The total noise power is reduced by matching the receiver bandwidth to the transmit bandwidth. The thermal noise contribution is further reduced by averaging many samples of the measured power and subtracting the estimated noise level. The number of independent samples can be increased by increasing the pulse repetition frequency *(PRF).* However, the maximum *PRF* is set by range ambiguity considerations. For CPR, the nominal range window size is set at 30 km and the nominal *PRF* of 3700 Hz is used. In flight, the *PRF* would vary slightly to accommodate for the change in orbital altitude.

In the baseline design, the CPR measurements along the nadir track are averaged in 0.48-sec time intervals. This corresponds to an effective along-track horizontal resolution of 3.8 km after averaging. The 0.48-s averaging at 3700 Hz provides nearly 1800 independent samples. The noise subtraction approach should allow signals that are 15 dB below the thermal noise to be detected. Table 1 shows the expected functional and performance parameters of CPR during normal operations.

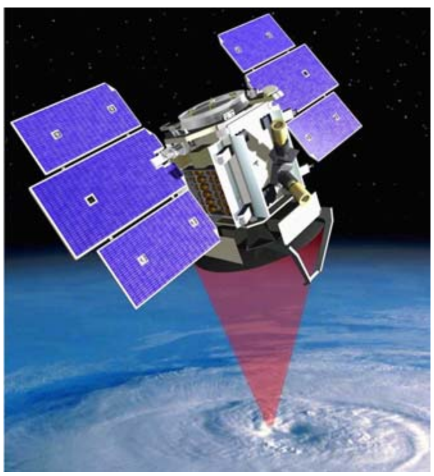

Figure 1: Cloud Profiling Radar (CPR) and CloudSat satellite in flight configuration.

Frequency	94.05 GHz
Altitude	705 km
Range resolution	500 m
Cross-track resolution	1.4 km
Along-track resolution	3.5 km
Pulse width	3.33 μs
Peak power (nominal)	1.7 kW
PRF	3700 Hz
Antenna diameter	1.85 m
Antenna gain (dBi)	63.1 dBi
Antenna sidelobes	-50 dB @ $\theta > 7^\circ$
Integration Time	0.48 sec
Data window	0 – 30 km
Minimum detectable reflectivity	-28 dBZ

Table 1: CPR instrument and performance parameters.

3. CPR HARDWARE DESCRIPTION

CPR is implemented by the following subsystems: Radio Frequency Electronics Subsystem (RFES), High-Power Amplifier (HPA), Antenna, Digital Subsystem (DSS), and Power Distribution Unit (PDU). The simplified version of the CPR instrument block diagram is shown in Figure 2.

The RFES **[Remi's paper, 3]** consists of an upconverter which accepts a 10 MHz oscillator signal from the DSS and upconverts it to a pulse-modulated 94 GHz signal. The signal is amplified to approximately 200 mW by a MMIC power amplifier. A switch within the upconverter is used to provide the modulation for generating pulses. The receiver accepts the received signal from the antenna and downconverts it to an intermediate frequency. A MMIC low-noise amplifier (LNA) provides the first stage of amplification. The gain of the LNA is large enough that additional stages have only a small contribution to the system noise temperature. The IF signal following downconversion is detected using a logarithmic amplifier.

The HPA, which amplifies the transmitted pulse to a nominal power level of 1.7 kW, consists of an extended interaction klystron (EIK) and a high-voltage power supply (HVPS). Both a primary and a backup HPA are used to enhance system reliability. Figure 3 shows one of the two CPR HPA flight models. The EIK tube is manufactured by Communications and Power Industries, Canada, Inc. The EIK differs from standard klystrons by using resonated bi-periodic ladder lines as a replacement for conventional klystron cavities. The high-voltage power supply (HVPS) provides 20 kV needed to operate the EIK and provides telemetry data necessary to system needs. The design uses a boost supply to minimize input current transients during the pulsing period and control EMC problems.

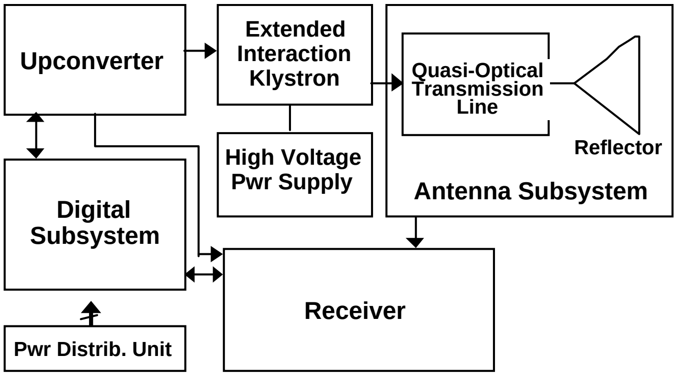

Figure 2: Simplified CPR block diagram.

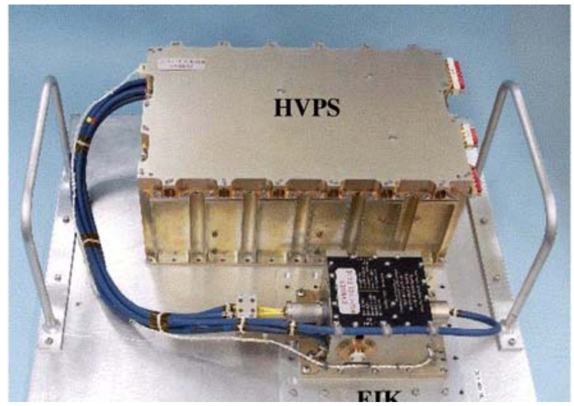

Figure 3: CPR High Power Amplifier flight model S/N-2.

The CPR Antenna Subsystem consists of the collimating antenna reflector and the quasi-optical transmission line (QOTL) [4]. The collimating antenna is a fixed 1.85-m diameter reflector, made from space-qualified composite graphite material to reduce mass. The antenna provides more than 63 dBi gain, has beamwidth < 0.12˚, and has sidelobes less than -50 dB for angles greater than or equal to 7˚ from boresight. This low sidelobe level is achieved using an offset feed design. Instead of using conventional waveguide, the antenna is fed by the QOTL for low loss. This QOTL approach is based on free-space transmission of Gaussian RF beams, with beam direction and focusing achieved by shaped metallic mirrors. The CPR Antenna Subsystem flight model is shown in Figure 4.

Figure 4: CPR Antenna Subsystem flight model.

The DSS provides the following functions: (1) receives commands from the spacecraft and transmits them in the correct format to the rest of the radar; (2) digitizes the telemetry from the rest of the radar and incorporates the digitized words in the science and telemetry data streams; (3) digitizes the radar echo, performs data processing and routes the data to the spacecraft data system for downlink; (4) generates the radar timing signals including the STALO; (5) routes the critical radar telemetry to spaceraft for real-time health monitoring. The Digital Data Handler (DDH) accepts the analog signal from the RFES logarithm detector. It digitizes the signal and performs the required averaging at each of 125 range bins. The averaged power is converted to a floating point format prior to being sent to the solid state recorder. The use of floating point reduces the required number of bits and data rate. No flight computer or flight software is used by DSS, most of the DSS functions are implemented using FPGAs.

The PDU accepts the nominal 28V DC prime power from the spacecraft, and converts the 28V input to appropriate secondary DC voltages to operate those lower voltage electronics subsystems. The PDU is based on commercial off-the-shelf power supplies. The PDU supplies power to the RFES, DSS, and the antenna subsystem (HPA selection switch). The HPAs accept the 28 V power from the spacecraft directly. The spacecraft also directly supplies 28 V power to replacement heaters. These will be operated whenever the radar is off, in order to maintain the electronics at temperatures within the survival range.

4. CURRENT STATUS AND SUMMARY

The Cloud Profiling Radar (CPR) for the CloudSat mission is a 94-GHz, nadir-pointing, high-power pulse radar. It will be the first-ever millimeter-wave and the most sensitive radar even launched into space. Its –28-dBZ detection sensitivity will enable the first global view of the vertical structure of the atmospheric clouds at 500-m resolution. While the radar is fairly straightforward from a functional point of view, the required technology at millimeter wave frequencies presented some challenges during the hardware implementation phase. As of October 2004, the CPR instrument flight model has been integrated into the spacecraft bus, and the functional/performance testing in the flight-like thermal/vacuum environment has been completed. The integrated CPR/spacecraft flight model is shown in Figure 5. The launch site preparation activities will begin in January 2005, leading to the scheduled launch in April 2005. After a brief post-launch checkout period, CPR will operate continuously throughout the mission life of two years.

Figure 5: The integrated CPR and CloudSat spacecraft bus flight unit.

ACKNOWLEDGMENT

The research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

[1] G. L. Stephens et al., "The CloudSat Mission and the A-Train," *Bull. Amer. Meteor. Soc.*, vol. 83, 1773-1789, 2002.

[2] J. R. Probert-Jones, "The radar equation for meteorology," *Quart. J. Royal Meteor. Soc.*, vol. 88, 485-495, 1962.

[3] Remie LaBelle paper.

[4] S. Spitz, A. Prata, J. Harrell, R. Perez, and W. Veruttipong, "A 94 GHz Spaceborne Cloud Profiling Radar Antenna System," *2001 IEEE Aerospace Conference Proceedings,* March 10-17, 2001.