

# Development Status of the Cloud Profiling Radar for the CloudSat Mission

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**Abstract** — The Cloud Profiling Radar, the primary science instrument of the CloudSat Mission, is a 94-GHz nadir-looking radar that measures the power backscattered by clouds as a function of distance from the radar. Shortly after the scheduled launch in November 2004, this instrument will acquire a global time series of vertical atmospheric cloud structure at 500-m vertical resolution and 1.4-km horizontal resolution throughout the nominal 2 year mission life. The cloud detection sensitivity of this instrument is expected to reach  $-28$  dBZ.

## I. INTRODUCTION

The CloudSat Mission [1] is a new satellite mission currently being developed by the National Aeronautics and Space Administration (NASA), the Jet Propulsion Laboratory (JPL), the Canadian Space Agency (CSA) 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 planned to launch in November 2004. 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. Figure 1 shows the operational geometry of CPR in formation-flying with several other science satellites. In this paper, we will present the system design and the expected performance of this instrument, as well as the current state of the development.

## II. SYSTEM DESIGN

The primary science objective for CPR is to achieve a minimum detectable cloud reflectivity ( $Z$ ) of  $-26$  dBZ at the end of the mission. This performance is needed since clouds are weak scatterers. By comparison the reflectivity for rain is typically 20-50 dBZ; the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) [2] has a sensitivity of around  $+17$  dBZ.

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



Figure 1: Cloud Profiling Radar (CPR) in formation-flying geometry.

received power and the noise level. The radar received power can be written as [3]

$$P_a(r) = \frac{P_t \lambda^2 G^2 \theta^2 \Delta \eta L}{512 \pi^2 \ln 2 r_a^2} \quad (1)$$

where  $P_t$  is the transmitter power,  $\lambda$  is the wavelength,  $G$  is the antenna gain,  $\theta$  is the antenna half-power beamwidth,  $\Delta$  is range resolution,  $r_a$  is the range to the atmospheric target,  $\eta$  is the cloud reflectivity<sup>1</sup>, 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 by increasing the radar frequency. On the other hand, signal absorption due to atmospheric gases may be prohibitively large at higher

frequencies. From these considerations, the use of 94 GHz provides an increase of 33 dB as compared with the use of the TRMM PR frequency of 14 GHz, and thus, allows the sensitivity requirement to be met using available technology.

Sensitivity is also related to the pulse length ( $\tau$ ). CPR will operate using 3.3- $\mu$ s 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. The exact *PRF* would vary to accommodate for the change in orbital altitude.

In the baseline design, the radar 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.

Table 1: CPR system parameters.

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 ms
Peak power (nominal)	1.7 kW
PRF	3700 Hz
Antenna diameter	1.85 m
Antenna gain (dBi)	63.1 dBi
Antenna sidelobes	-50 dB @ $q > 7^\circ$
Integration Time	0.48 sec
Data window	0 – 30 km
Minimum detectable reflectivity	-28 dBZ

### III. HARDWARE IMPLEMENTATION

CPR is implemented by the following subsystems: Radio Frequency Electronics Subsystem (RFES), High-Power Amplifier (HPA), Antenna, and Digital Subsystem (DSS). The simplified version of the CPR instrument block diagram is shown in Figure 2. The RFES 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 (IF). 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; this approach has been used on the TRMM PR to provide high dynamic range [2].

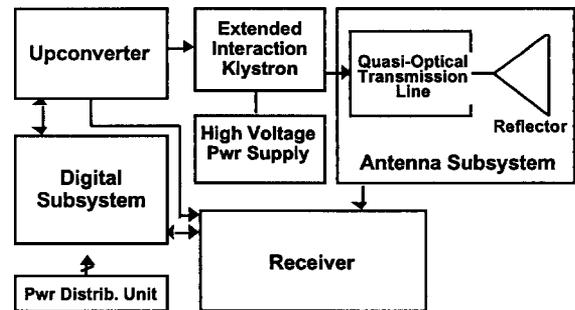


Figure 2.: Simplified CPR block diagram.

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. 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. As of May 2003, two EIK flight models have been built and fully tested. The first EIK flight model is shown in Figure 3. 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. The HVPS engineering model is shown in Figure 4.

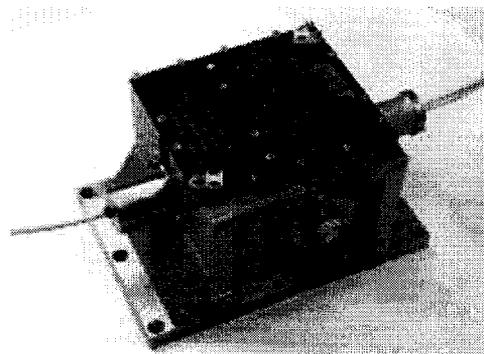


Figure 3: The first flight model of the CPR's 94-GHz EIK.

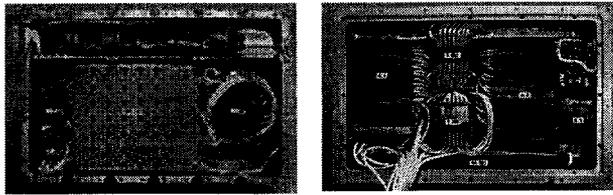


Figure 4: The first flight model of the CPR's HVPS. The grid modulator is at left, and the cathode and collector modules are at right.

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  $< 0.12^\circ$ , and has sidelobes less than -50 dB for angles greater than or equal to  $7^\circ$  from boresight. This low sidelobe level is achieved using an offset feed design. In stead 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 5.



Figure 5: CPR Antenna Subsystem flight model.

The DSS provides the following functions: (1) to receive commands from the spacecraft and transmit them in the correct format to the rest of the radar; (2) to digitize the telemetry from the rest of the radar and incorporate the digitized words in the science and telemetry data streams; (3) to digitize the radar echo, do simple data processing and transmit the data to the as part of the science data stream to be downlinked to earth; (4) to generate the radar timing signals including the STALO; (5) to generate the radar signal that will be upconverted from L-Band to 94 GHz in the RFES and transmitted by the HPA. The first four functions are done in the Control and Timing Unit (CTU) portion of the DSS. 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. Owing to its simplicity, much of the DSS is implemented using FPGAs. No flight computer or flight software is used by DSS in order to reduce development time and cost.

Power for CPR is provided by a Power Distribution Unit (PDU). 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 HPA's 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.

#### IV. SUMMARY

The Cloud Profiling Radar (CPR) on the CloudSat mission will provide the first global view of the vertical structure of clouds. It is a nadir-looking radar operating at 94 GHz. While the radar is fairly straightforward from a functional point of view, the required technology at millimeter wave frequencies presents some challenges. Currently, CPR instrument flight model is at the final stage of its integration and ambient test phase, leading to detailed environmental testing in the simulated flight conditions. CPR is planned to be launched in late 2004, and will operate continuously throughout the mission life of two years.

#### ACKNOWLEDGMENT

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