CloudSat Radar Instrument Design and Development Status

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***Abstract* — The Cloud Profiling Radar is the key science instrument for the CloudSat Mission to acquire a global data set of vertical atmospheric cloud structure and its variability. CPR is a 94-GHz nadir-looking radar that measures the power backscattered by clouds as a function of distance from the radar. This sensor is expected to provide cloud measurements at a 500-m vertical resolution and a 1.5-km horizontal resolution. CPR will operate in a short-pulse mode and will yield measurements at a minimum detectable sensitivity of -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), and 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 early summer of 2003. One key 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 this paper, we will present the system design and the expected performance of this instrument, as well as the state-of-the art millimeter-wave technologies employed by this instrument.

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 +20 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 received power and the noise level. The radar received power can be written as [3]

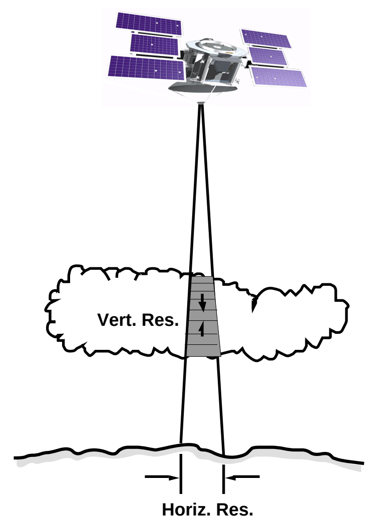

Figure 1. Cloud Profiling Radar (CPR) operational geometry.

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

where P_t is the transmitter power, 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 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 (τ). CPR will

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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 4300 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 0.32-sec time intervals. This corresponds to an effective along-track horizontal resolution of 3.5 km after averaging. In order to provide enhanced capability to discriminate cloud features, the CPR measurements are sampled at 250-m in range, and 0.16-s along the nadir track. The 0.32-s averaging at 4300 Hz provides nearly 1400 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	720 km
Range resolution	507 m
Cross-track resolution	1.4 km
Along-track resolution	3.5 km
Pulse width	3.33 µs
Peak power (end of life)	1.6 kW
PRF	4300 Hz
Antenna diameter	1.85 m
Antenna gain (dBi)	62 dBi
Antenna sidelobes	-50 dB @ θ > 7˚
Integration Time	0.48 sec
Data window	0 – 25 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].

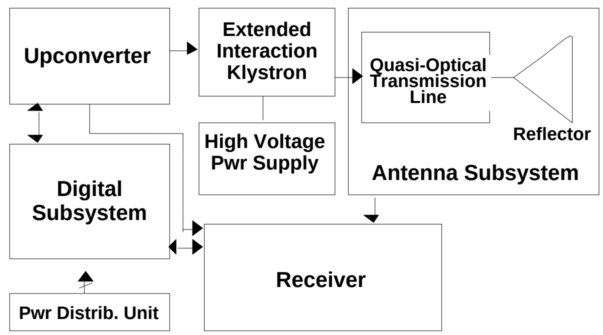

Figure 2. Simplified CPR block diagram.

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 a space-qualified version of a commercial tube, 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. In 2000, the second EIK engineering model as shown in Figure 3 was built and fully tested. The high-voltage power supply (HVPS) provides 1.9 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.

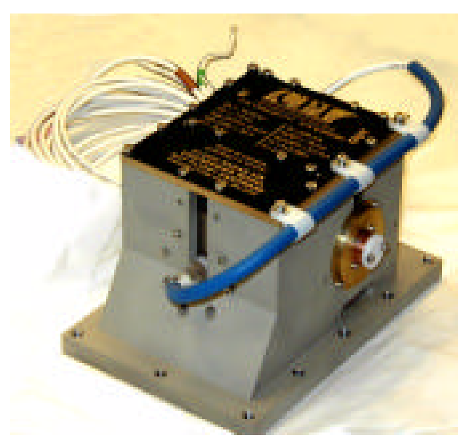

Figure 3. The second engineering model of the CPR's 94-GHz EIK.

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. 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 is graphically illustrated in Figure 4.

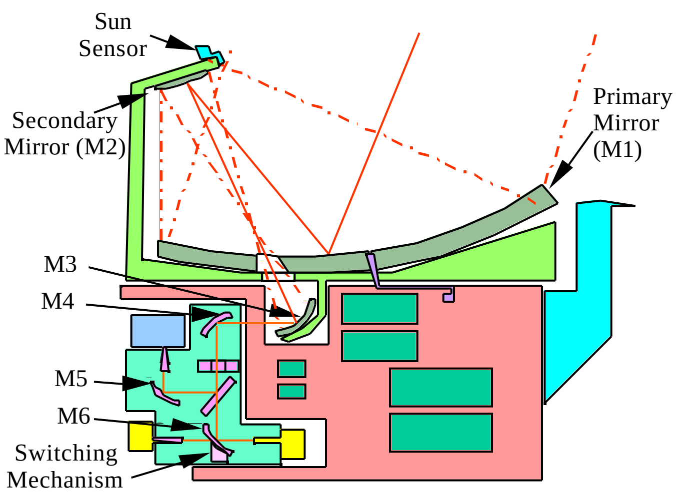

Figure 4. Graphical illustration of the CPR Antenna Subsystem.

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. Conclusions

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 is in the detailed design phase, leading to the Critical Design Review in August 2001. CPR is planned to be launched in mid 2003, and is designed to operate continuously over the next two years.

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