SCIENTIFIC AND ENGINEERING OVERVIEW OF THE NASA DUAL-FREQUENCY DUAL-POLARIZED DOPPLER RADAR (D3R) SYSTEM FOR GPM GROUND VALIDATION

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ABSTRACT

As an integral part of Global Precipitation Measurement (GPM) mission, Ground Validation (GV) program proposes to establish an independent global cross-validation process to characterize errors and quantify uncertainties in the precipitation measurements of the GPM program. A ground-based Dual-Frequency Dual-Polarized Doppler Radar (D3R) that will provide measurements at the two broadly separated frequencies (Ku- and Ka-band) is currently being developed to enable GPM ground validation, enhance understanding of the microphysical interpretation of precipitation and facilitate improvement of retrieval algorithms. The first generation D3R design will comprise of two separate co-aligned single-frequency antenna units mounted on a common pedestal with dual-frequency dual-polarized solid-state transmitter. This paper describes the salient features of this radar, the system concept and its engineering design challenges.

***Index Terms*—** GPM, ground validation, D3R, Dual-frequency radar, TRMM

1. INTRODUCTION

The scientific understanding of the global water cycle requires detailed knowledge of vertical precipitation structure and the mesoscale physical structure of rain systems on a global scale and those can only be directly obtained by a spaceborne radar. The successful introduction of a single-frequency (Ku-Band: 13.8 GHz) Precipitation Radar (PR) onboard the Tropical Rainfall Measuring Mission (TRMM) satellite in 1997 facilitated improved understanding of the spatial distribution, variability, intensity of rainfall and its role in climate in tropical and subtropical regions [1]. As a follow-on mission to TRMM, the Global Precipitation Measurement (GPM) mission will attempt to advance further the goal of making global scale precipitation observations to higher latitudes with more frequent sampling by deploying the next generation of satellite-borne weather radars.

The GPM core satellite will carry a Ka-Ku band Dual-frequency Precipitation Radar (DPR) [2] that can make multi-parameter measurements of precipitation directly related to the microphysical rain structure (such as raindrop size distribution and vertical water content profiles). While the Ku-band radar is an advanced, high-resolution version of the TRMM precipitation radar, the Ka-band radar would provide higher sensitivity which can prove useful in the measurement of snow and light rain. To ensure desired accuracy and validation of DPR measurements as well as enhance robustness of the retrieval algorithms, GPM will employ a comprehensive and global ground validation (GV) program [3]. The Dual-Frequency Dual-Polarized Doppler Radar (D3R) is a ground validation radar for the GPM-GV program which is currently being jointly developed by NASA Goddard Space Flight Center, Colorado State University and Remote Sensing Solutions. This paper provides a scientific overview of the D3R system as well as major engineering challenges associated with its development and integration.

2. SCIENTIFIC OBJECTIVES OF D3R

The preferred frequency bands of operation for precipitation surveillance in ground radar systems have been nearly non-attenuating frequencies (such as S-, C-band) or short-range measurements of attenuating frequencies (as in X band). But it is not practical to use traditional ground-based weather radar frequencies (such as S- or C-band) for space-borne precipitation radars because of the limitations imposed by the size of the satellite-mounted antenna and the power available. On the other hand, moving to the higher frequencies to observe precipitation offers the challenge of attenuation due to precipitation. The Ku-band frequency in TRMM PR was successfully demonstrated to be very useful for tropical rain profiling [4]. However, TRMM's center-frequency (13.8 GHz) is less sensitive to backscatter from smaller raindrops. Therefore, the GPM mission has

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embarked on a dual-frequency approach at Ku- and Ka-band for characterizing precipitation. Ka-band, in particular, would considerably increase the radar's sensitivity towards light rain, drizzle and snow and also offer excellent spatial resolution. In addition, the dual-frequency system provides a mechanism for retrieving the raindrop size distribution.

The GPM-GV D3R is a dual-frequency ground-based radar which provides for various options, including polarimetry and Doppler capabilities. Polarimetry is critical for understanding the microphysics and, in the recent times, extensive use of polarimetric radar systems at higher frequencies has been made feasible by advances in attenuation correction methods based on polarimetric measurements [5]. Doppler measurements are useful for linking the dynamics with the microphysics of precipitation structure. Thus, as a value-added validation instrument, it is very useful to have both dual-polarization and Doppler measurement. Hence, the name D3R or Dual-frequency Dual-polarized Doppler Radar. The scientific goals of D3R extend over several seminal research areas, some of which include the following:

Enrich dual-frequency database: While extensive ground radar observations of precipitation are available at S- and C-band, such measurements do not exist at Ku- and Ka-band. Ground radar measurements enjoy the advantage of coincident microphysical observations available to interpret radar signatures. An important broader science goal of the NASA D3R is to enhance the database of dual-frequency radar observations on the ground, in conjunction with existing observations, in order to provide a dataset for physical validation.

Microphysical Characterization: Dual polarization radar observations can be used operationally to not only improve the data quality of a standard Doppler radar but also improve precipitation measurement accuracy and provide a basis for hydrometeor classification. D3R is aimed to yield enhanced microphysical characterization similar to what has been done at lower frequencies.

Error Characterization: The self-consistency of dual-polarization and dual-frequency observations presents an additional level of interpretation. With the ground-based D3R, an independent estimation of hydrometeor classification and drop size distribution retrievals can be carried out to understand the error structure of retrievals. Thus, the radar will also offer an insight into the physics of the retrieval processes and the associated measurement errors.

Algorithm Improvement: The current spaceborne retrieval algorithms are susceptible to various sources of errors which include assumptions regarding DSD parameters, vertical extent of liquid water and ice content, attenuation due to clouds and horizontal variations of precipitation in a remote resolution cell. In this respect, D3R can provide anchor points for the global retrieval algorithms used in GPM DPR. While the DPR will present a global picture of precipitation through observations at Ku- and Ka-band, the ground-based D3R will yield detailed fine-scale local statistics of the microphysical interpretation.

3. ENGINEERING CONSIDERATIONS

Table 1 lists the technical specifications of the D3R system. D3R is being developed as a fully polarimetric, scanning weather radar system operating at the nominal frequencies of 13.9 GHz and 35.5 GHz covering a maximum range of 30 km. The frequencies chosen allow close compatibility with the GPM DPR system. The implementation of the dual-polarization technology is achieved by providing sufficient cross-pol isolation and cross-polarized backscatter detection capability as noted on Table 1. The sensitivity of the system at both frequencies is pegged at -10 dBZ at 15 km to enable snow measurements, which can document the "missing tail" in the current snow observations from GPM DPR.

Figure 1 shows the CAD visualization of the D3R system mounted on a mobile trailer platform. Some of the salient engineering design aspects of D3R include the following:

Aligned antennas: An important engineering aspect of a dual-frequency system is the level of "integration". This can range from a design where two separate radar units operate independently to the one that employs a common reference system for dual transmitters on a single dual-frequency aperture. The first generation version of the D3R falls somewhere in the middle, i.e., a common platform transmitter illuminating two distinct but aligned antennas. There are future plans to migrate to a single aperture system.

Solid-state transceiver: Rain-profiling and reliable detection of cross-pol rain backscatter demand substantially higher peak power. One of the novel aspects of D3R is that it employs a solid-state transceiver which can considerably enhance the sensitivity of the radar by also allowing implementation of pulse compression [6]. Furthermore, the use of a solid-state transmitter also enables the deployment of D3R at very different and extreme climatic locations. A companion paper in this conference discusses the technical details of the realization of the solid-state transmitter/receiver system [7]. A multi-channel digital receiver which would implement frequency-diversity pulse compression for D3R is also under development as described in [8].

System Architecture: The transceivers, waveform generator and digital receivers are mounted on the back of the respective antennas and form the rotating subsystems of the radar (Figure 2). The time series and positioner data is transferred to the dedicated moment generation servers over two Gigabit links. These servers provide the processed data to remote and local real-time displays, a remote dual-frequency derived products server and a data archiving node. The entire system is configured and commanded by a system controller node.

Retrieval algorithms: The dual-frequency dual-polarization operation at higher frequencies involves non-Rayleigh scattering mechanisms and presents different precipitation signatures compared to the conventional S- or C- band observations. Indeed, most of the engineering challenges stem from making precipitation measurements on the ground at a highly attenuating frequency. For instance, traditional dual-pol DSD retrieval algorithms for ground-based radar using φ_{dp} are not suitable at Ka-band. In order to support the development, extensive numerical evaluations have been carried out to document the extinction statistics of propagation through precipitation and new parameter retrieval techniques by combining dual-frequency and dual-polarization observations have been investigated [9].

4. SUMMARY

The D3R system is in an advanced phase of development. The integration of the subsystems is scheduled to be completed by 2010 and current state of design and development is progressing well. The radar expects first deployment in the year 2011.

5. ACKNOWLEDGEMENT

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TABLE 1
D3R RADAR PARAMETERS

System	
Frequency	Ku: 13.91GHz ± 25 MHz Ka: 35.56GHz ± 25MHz
Minimum detectable signal (Ku, Ka)	-10dBZ at 15 km for a single pulse at 150m range resolution
Minimum operational range	450 m
Operational range resolution	150 m (nominal)
Maximum range	30 km
Angular coverage	0-360° Az, -0.5-90° El (full hemisphere)
Antenna	
Parabolic reflector (diameter)	6ft/72in (Ku), 28in (Ka)
Gain	44.5 dB (Ku, Ka)
HPBW	~1° (Ku, Ka)
Polarization	Dual linear simultaneous and alternate (H and V) (Ku, Ka)
Maximum sidelobe level	~ -25 dB (Ku, Ka)
Cross-polarization isolation	< -32 dB (on axis)
Ka-Ku beam alignment	Within 0.2°
Scan capability	0-24°/s Az, 0-12°/s El
Scan types	PPI sector, RHI, Surveillance, Vertical pointing
Transmitter/Receiver	
Transmitter architecture	Solid state power amplifier modules
Peak power/Duty cycle	160 W (Ku), 40 W (Ka) per H and V channel, Max duty cycle 30%
Receiver noise figure	4.6 (Ku), 5.5 (Ka)
Receiver dynamic range	≥ 90 dB (Ku, Ka)
Clutter suppression	GMAP
Data Products	
Standard products	Equivalent reflectivity factor Z_h (Ku, Ka), Doppler velocity (unambiguous: 25 m/s)
Dual-polarization products (Ku, Ka) (LDR only in alternate transmit mode)	Differential reflectivity Z_{dr} Differential propagation phase φ_{dp} Copolar correlation coefficient ρ_{hv} Linear depolarization ratios LDR_h, LDR_v
Data format	NetCDF

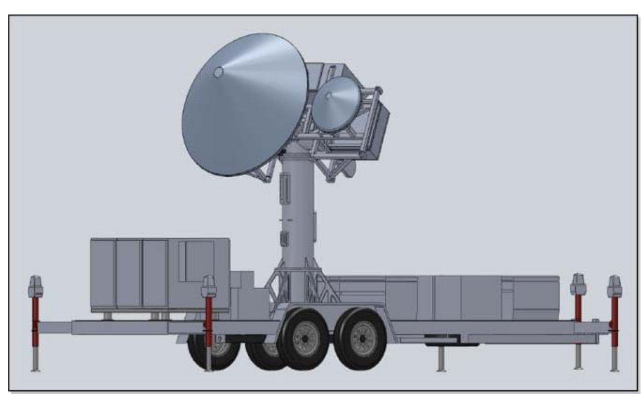

Figure 1. CAD model of D3R system.

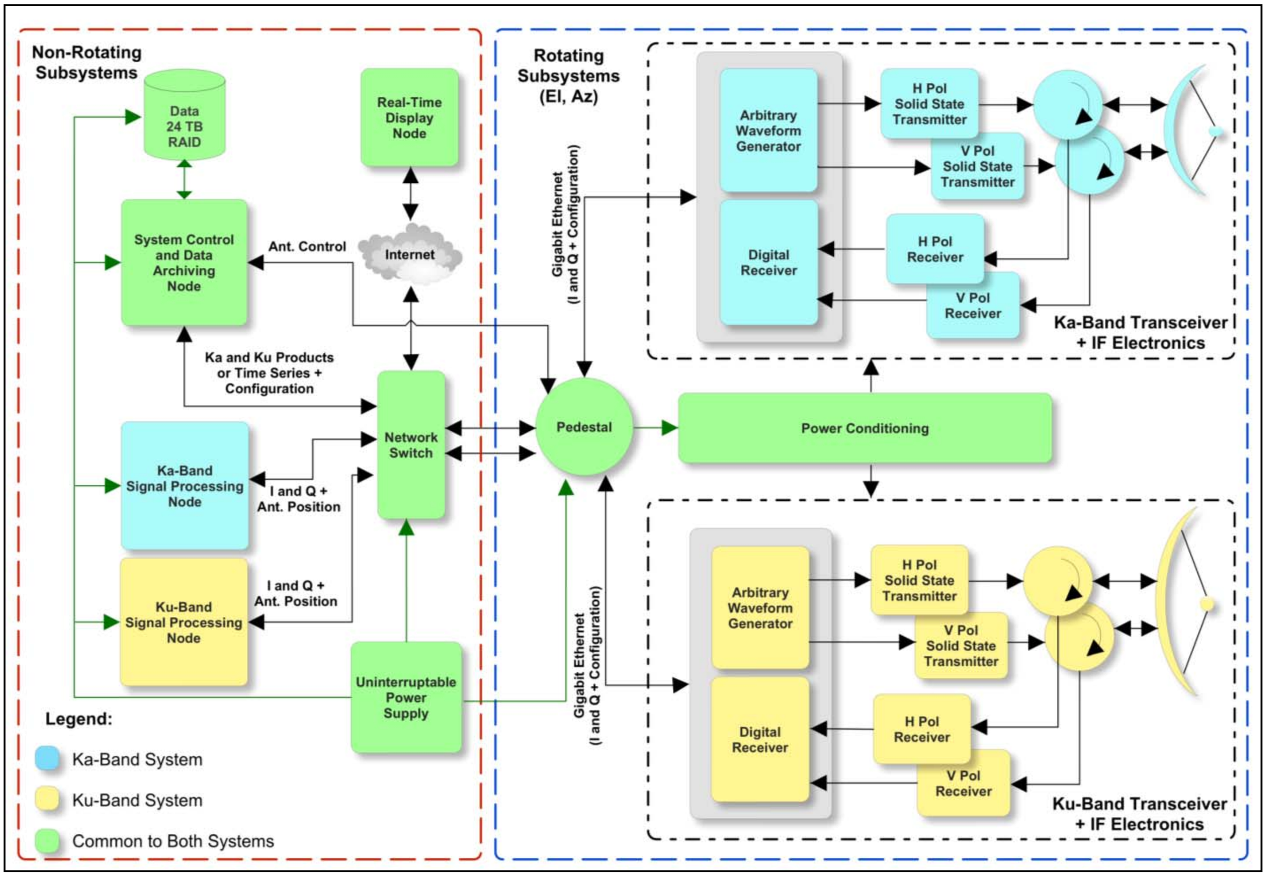

Figure 2. System architecture of D3R radar.

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