Title of Investigation:

Forward and Backscattering Measurements of Rainfall Using the NASA Microwave Link

Principal Investigators:

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Other External Collaborators:

Roger H. Lang (George Washington University)

Initiation Year:

FY 2004

FY 2004 Authorized Funding:

$57,000

Actual or Expected Expenditure of FY 2004 Funding:

Hardware/Software: $23,000; Tech Support Contracts: $17,000; University Cooperative Agreement: $17,000

Status of Investigation at End of FY 2004:

Completed in FY 2004: Backscatter link prototyping and lab testing.
To be continued in FY 2005:

Rainfall measurements at Wallops Island with prototype system and obtain Independent Research & Development (I&RD) funding for permanent system modifications.

Expected Completion Date:

September 2005

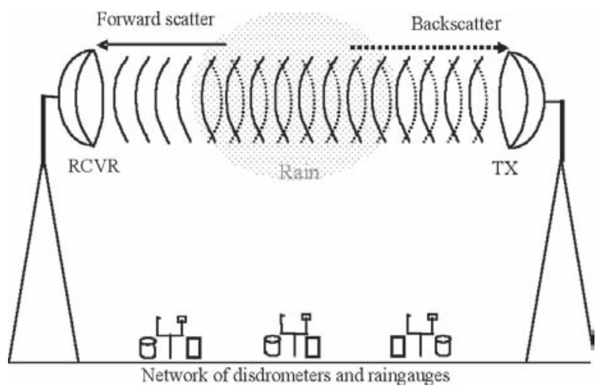
Purpose of Investigation:

Estimating and validating rainfall is a difficult and challenging endeavor due to variability inherent in the process. Microwave radars estimate rainfall by transmitting energy pulses through the rain and measuring the power that reflects back (backscatter) from the raindrops. For many years, ground and airborne microwave weather radars— and more recently spaceborne microwave weather radars—have relied on data collected on the ground surface using disdrometers, devices that measure the size of the raindrops, and rain gauges, to test and validate the algorithms that scientists use to estimate rainfall. However, discrepancies between the radar rainfall estimates and the measurements from the disdrometers and rain gauges on the ground have been significant. In an attempt to address this problem, this project studied the feasibility of upgrading another type of microwave rainfall-measuring instrument, the NASA Wallops Microwave Link System, to provide more accurate estimates of rainfall.

In particular, this project studied incorporating radar measurements into the Wallops Microwave Link System. The Microwave Link System is a research instrument that measures the forward-scattering properties of rain between the transmitting and receiving antennas. Forward-scatter measurements provide information about bulk rainfall over the signal-propagation path. (See Fig.

1.) The Microwave Link System operates just above a network of disdrometers and rain gauges that provide real-time rainfall measurements. By upgrading the Microwave Link System with backscatter measurement capability, we can estimate important rainfall parameters, such as the drop size distribution (DSD) and the rainfall rate, at fine spatial scales permitting better comparisons with the ground measurements and enabling a more detailed study of the rainfall process. The forward and backscatter microwave link, along with the network of disdrometers and rain gauges, thus provides a uniquely controlled environment for the testing and the development of rainfall retrieval algorithms. The effort will largely improve rainfall estimation and validation and could lead to a new generation of rainfall validation instruments — especially valuable to the Tropical Rain Measuring Mission (TRMM) and the upcoming Global Precipitation Mission (GPM). The concept of a forward- and backscattering-measuring Microwave Link is shown in Figure 1.

Figure 1. The Microwave Link transmitter and receiver antennas are separated by 2.3-km path and elevated 20 m above the ground. A ground network of disdrometers and rain gauges located under the path serves as ground validation.

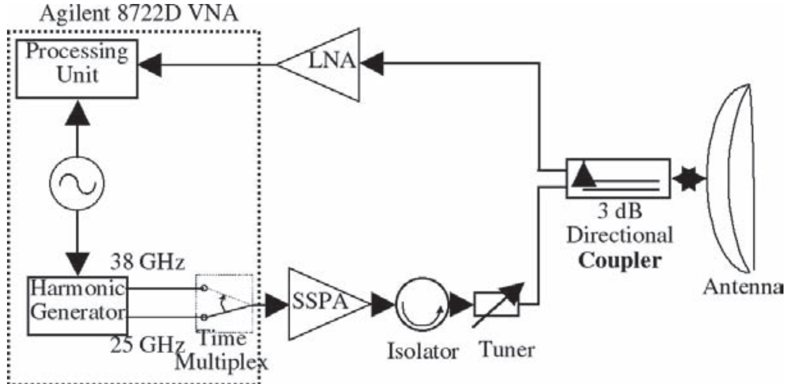


FY 2004 Accomplishments:

Incorporating backscatter measurements into the existing Microwave Link system requires substantial modification of both the Link transmitter and the Link receiver. As an intermediate step, the project used a Vector Network Analyzer (VNA) as a Frequency Modulated Continuous Wave (FMCW) radar at two of the Link frequencies to provide simultaneous forward and backscatter measurements of rainfall. The flexibility inherent in the VNA permitted us to test several FMCW radar parameters and then select the optimum design for a permanent FMCW radar system. The FMCW radar is operated either in a single-frequency mode at 25 GHz or 38GHz, or in a dual-frequency mode at both frequencies. In the dual-frequency mode, the VNA is switched rapidly between the two frequencies. The Microwave Link dual-frequency transmitter antenna is used to transmit and receive the radar signals. The VNA can be remotely controlled via a GPIB bus or Ethernet connection and automated with PC software.

Figure 2 shows the schematic of the FMCW radar configuration implemented with a HP 8722D VNA. The current configuration uses two amplifiers, an isolator, a stub tuner, a directional coupler, and an antenna.

Figure 2. Schematic of the FMCW radar implementation using the VNA.



A theoretical analysis was performed to check the feasibility of rainfall measurements using the VNA, the 25 Ghz and 38 GHz Link frequencies. The analysis employed measured path-averaged DSDs with disdrometers over the 2.3-km Link propagation path. The network analyzer sweeps over a frequency range of bandwidth B = 0.6 MHz. The return from each frequency is coherently detected, and then the total return signals is Fourier transformed to obtain the time domain response. The range resolution achieved is $\Delta r = c / 2B$, where c is the speed of light. Hence, if a 250-m resolution is desired (distance between gauges under the Link site), a frequency bandwidth of 0.6 MHz would be required. The range ambiguity is determined by $r_u = c / 2 \Delta f$, where Δf is the receiver filter bandwidth. When the analyzer samples the return signal frequencies at 201 intervals (points), each frequency would be separated by 3 KHz. This implies an ambiguity range of 50 km. Hence, over the Link path of 2.3 km no ambiguity problems will occur. The results from the theoretical calculations are plotted in Figure 3a for 25GHz and in Figure 3b for 38GHz. The results were obtained using the radar parameters listed in Table 1. Each graph shows the normalized backscattered power as a function of the range for several rainfall intensities.

Table 1. Radar parameters employed in the theoretical analysis:

Frequency (GHz)	25.35	38.025
Wavelength (cm)	1.18	0.79
Gain (dB)	47	50
Beamwidth (deg)	0.7	0.6
Bandwidth (MHz)	0.6	0.6
Filter Bandwidth (KHz)	3	3
Range Resolution (m)	250	250

The implementation of the FMCW radar using the VNA allowed us to test different output power levels, range resolutions, and unambiguous ranges. The results showed us how to optimize the different radar parameters. The laboratory tests included rainfall measurements with the FMCW radar and an impact disdrometer on top of the roof of building 33. The measurements showed high correlation between the radar power measurements and the rain rates measured by the disdrometer. We also have made significant progress in the development of the rain-retrieval algorithms. Our research associate from the George Washington University has implemented two important rainfall algorithms, the forward- and backward-recursion algorithms in Matlab. In addition, we have been able to make minor modifications to the backward-recursion algorithm that improves the rainfall retrievals along the Wallops Link path.

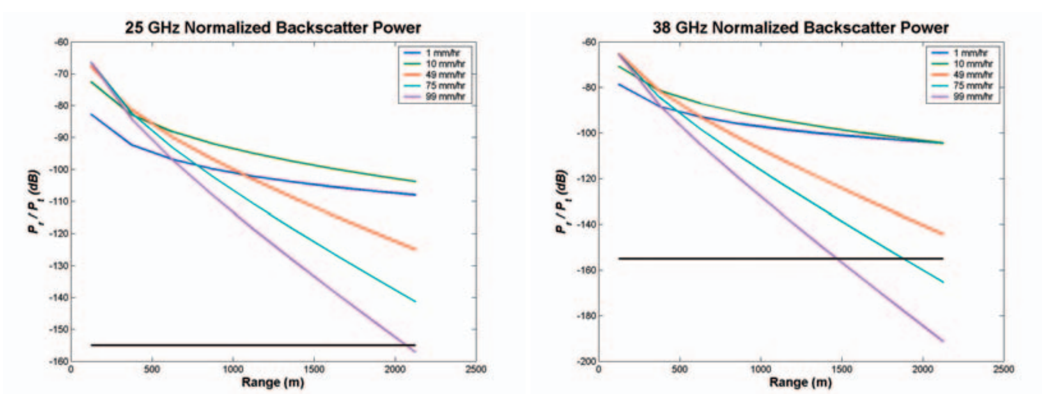


Figure 3. Normalized Received Power (dB) versus Range (km) for light, moderate and heavy rain at a) 25 GHz and b) 38 GHz.

The concept and preliminary work on the Forward and Backscattering Measurements of Rainfall using the NASA Microwave Link were presented at the IGARSS 2004 conference in Anchorage, Alaska. Work progress and additional results also were presented at the URSI 2005 conference in Denver, Colorado.

Planned Future Work:

The prototype FMCW radar will be installed soon at the Microwave Link site on Wallops Island, where we will concentrate on collecting and analyzing data sets for a significant number of rain events. The data sets will be used to test single- and dual-frequency radar-retrieval algorithms. The rain rates and DSDs obtained will be compared with the rain gauge and disdrometer measurements on the ground at various range cells to check their validity.

Summary:

The project studied the feasibility of upgrading the existing NASA Microwave Link System by configuring a VNA to operate as horizontally looking FMCW radar along a path. The upgraded system will act naturally as a test bed for testing and validating TRMM and GPM rain-retrieval algorithms. The measurements also will lead to the development of new rainfall-retrieval algorithms. A unique aspect of this measurement system is that supporting disdrometers and rain gauges are immediately below the radar-scattering cell, providing a tightly controlled research environment.

Our current accomplishments include: 1) making theoretical calculations for power budget specifications and hardware design; 2) procuring hardware components required to implement the FMCW radar; 3) developing and testing C++ software to remotely control the VNA with a personal computer; 4) implementing and testing the FMCW radar in the lab; 5) developing Matlab programs to implement the algorithms that estimate rainfall; and 6) taking preliminary reflectivity measurements using an FMCW radar in the laboratory.

The proposed efforts support the Goddard Space Flight Center's Earth science mission because they research ground-based measurements and theoretical investigations that complement space measurements. The combined backscatter- and forward-scatter measurements and the measurements from an existing ground-based network of rain gauges and disdrometers will make the Wallops Island facility an excellent verification site for the upcoming GPM. In addition, the overall efforts will serve as the experimental test bed for validating spaceborne weather radar-retrieval algorithms and developing new rainfall-retrieval techniques.