A LABORATORY STUDY FOR DUAL-POLARIZATION SCATTERING CHARACTERISTICS OF METEOROLOGICAL OBJECTS

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1. INTRODUCTION

The radar sensors with dual-polarization capability allow better understanding and characterization of weather hazards. Advanced knowledge-based hazard detection algorithms would require better knowledge of wave scattering characteristics of hydrometeors such as raindrops, hailstones, and snowflakes. Especially, scattering characteristics becomes important for optimally utilize phase-array dual-polarization radar systems. Traditionally, theoretical approaches [1] have been used to calculate the scattering characteristics while controlled lab-measurements have not been fully explored. In this abstract, an experimental approach is adopted with the assistance of a controlled laboratory environment. The advanced Agilent PNA network analyzer-based scatterometer system design is introduced. The key Radar Cross-Section (RCS) parameters and preliminary validation through actual scattering measurements are discussed.

It is expected that the calibrated scatterometer system can be used to characterize emulated or natural weather hazard samples. While it is known that the actual meteorological targets are generally considered as random and distributed targets consisting of a large volume of point scatterers, and the volume scattering field can be viewed as the superposition of all the point scatterers in the radar resolution volume, as a first-order solution of N-particle scattering problem [2]:

\[ F(\kappa_i, \kappa_j) = \sum_{p=1}^{N} f_p \exp \left( \frac{j \mathbf{k}_p \cdot \mathbf{r}}{\lambda} \right), \]

where \( F \) is the total scattering amplitude of the \( E \) field, \( f_p \) is the scattering coefficient of the \( p \)th particle, \( \mathbf{k}_p \) and \( \mathbf{r} \) are the direction vector for scattering and incidental wave, respectively, \( \mathbf{r} = \mathbf{k}_p - \mathbf{r} \) and \( \mathbf{r} \) is the position vector of the \( p \)th scatterer. From (1), it is important to understand the scattering properties for each individual scatterer before extending to the entire volume scattering situation. This approach requires the knowledge of amplitude, phase and frequency variation of the bi-static scattering for a single scatterer. The lab measurement can be combined with simulation prediction to validate this knowledge.

In additional to traditional theoretical tools, a fast method to simulate dual-polarized RCS for single or small number of scatterers with arbitrary shape/orientation is using commercial EM solvers (such as HFSS®), and then a Monte-Carlo simulation can be run to predict the volume scattering of a large number of identical scatterers. The simulation results can then be compared with lab measurement for verification. Because of the sensitivity limitation of the scatterometer system, the simulation data should be combined with lab measurement as a preferable source about the knowledge of very small particles.

2. THE SYSTEM SETUP AND CALIBRATION

A PNA E8364B network analyzer is being used as a centerpiece for performing various in-door measurements. The PNA system is powerful equipment from Agilent which simplifies the traditional antenna and RCS measurement process. This multi-function scatterometer, which can cover from S-band to Ku-band (3-18 GHz) with a simple system configuration, can emulate continuous wave transmit signal at different frequencies as well as the pulsed waveform of a phased-array radar. The conceptual scatterometer configuration is set up as shown in Figure 1. Thus far, the internal gating contained in the PNA network analyzer has been sufficient so that no external gating hardware has been required. The dimensions of the range are such that far-field requirements are met and the height of the antennas from the ground is sufficient to control ground reflection and sidelobe interference. The scatterometer has the parameters listed in Table 1, which make it well suited for the in-door RCS characterizations.

<table>
<thead>
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<th>Table 1: System parameters of the scatterometer</th>
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<td>Frequency coverage</td>
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<td>Transmit power</td>
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The chamber itself has been lined with standard radar-absorbing foam along all significant surfaces. This and other modifications have resulted in a transmit-to-receive power ratio of -90 dB in the frequency domain and -110 dB in the time domain for the empty range. A rig has been specially designed to allow the suspension of different-sized targets using a low εr net constructed of monofilament. The rig allows the target to be stably suspended and allows the height of the target to be adjusted from behind the antennas without needing to go downrange.

For a single scatterer, the dual-polarized RCS is measured from radar range equation:

$$\frac{P_{r(h,v)}}{P_{t(h,v)}} = \frac{G_r G_t \lambda^2}{(4\pi)^2 R^4} \sigma_{(h,v)},$$  \hspace{1cm} (2)

where \(P_r\) is the received signal power for multiple polarizations, \(P_t\) is the transmit signal power for multiple polarizations, \(\lambda\) is the wavelength, and \(R\) is the range of the target under test. \(G_r\) and \(G_t\) denote transmit and receive antenna gain, respectively, and vary with wavelength according to the antenna specifications. \(\sigma_{(h,v)}\) is the multi-polarized RCS to be measured. From (2), RCS can be derived by measuring T-R power ratio at specific frequencies for a fixed-range target.

The scatterometer is calibrated with aluminum spheres with different diameters. A comparison of a scatterer’s RCS measured from (2) to the theoretical results obtained from Mie scattering theory approximation shows an excellent correlation as shown in Figure 2.

3. PRELIMINARY MEASUREMENT RESULTS OF SOME EMULATED METEORLOGICAL TARGETS

At this time, our current lab-measurement effort focuses on the frequency variation of the dual-polarized mono-static RCS for small number of meteorological scatterers. Also, we focused on comparing the dual-polarized RCS of emulated metrological targets with a perfect conductor sphere at X-band. The scattering phase measurement and large-volume scattering results will be reported later as experimental data and theoretical models are developed.

3.1 Large emulated ice balls

Measurement results with a 3.6” diameter man-made ‘super hailstone’ are shown in Figure 3-4. Spheres were constructed of uniform ice as well as layered ice of differing densities. This was accomplished by using ice.
from different sources frozen in succession. The large size of the spheres permitted strong measurements with radar and gave information that can be applied to smaller particles less easy to individually measure. Initial measurements show a difference in $\sigma_{hh}$ and $\sigma_{vv}$ for the ice balls, as well as greater fluctuation across the frequency range. The discrepancy in vertical to horizontal RCS response can also be observed in theoretical predictions at 10 GHz. This can prove useful in identifying and classifying specific hydrometeors.

3.2 Iced-filled ping-pong ball
As a more realistic emulation of the natural hail storm (particularly in size of the hail), ice-filled ping-pong balls (1.5” diameter) are measured using the scatterometer system. A single ice-filled ping-pong ball yields $\sim$10 dB signal-to-noise ratio at 2.0-meter (far field) measurement distance. A typical measurement result is shown in Figure 5. Again, a difference in the vertical and horizontal RCS is observed.

3.3 Small scale clustered/volume scatterers
The next step in the experiment is to create a volume distribution of ice spheres. This work is still in progress while some simple volume-scattering tests by fast measuring clusters of 1.5-inch ice spheres has been performed. The ice-spheres are suspended in a net made with low-$\varepsilon_r$ monofilament and agitated to emulate random motion and distribution. 60 points of RCS data samples are obtained and averaged from 9 to 9.5 GHz frequency range. As we can see from the example in Figure 7, the $\sigma_{VV}$ measurement shows a slight increase of RCS from single sphere to a stack of 3 spheres, while a larger increase in RCS is observed for stacks of 4 and 5 spheres. The figure also illustrates the importance of phase information when characterizing hydrometers. The phase of the backscattered radiation is dependent on the size of the cluster, and so can give information regarding the makeup of a volume distribution of ice spheres.
RCS for Clusters of 1.5” Ice Spheres

![RCS graph](image)

**Figure 6:** Example measurement results of $\sigma_{vv}$, which compares the RCS of background noise, a single ice sphere, 3-ball, 4-ball and 5-ball clusters.

### 4. EXPLOITING THE PHASE INFORMATION OF SCATTERING FIELDS

For more advanced distributed target characterization and hazard classification, the complex (bi-static) RCS $\sigma$ is also a key parameter for the polarimetric scattering characterization. In HFSS, the complex RCS is defined as

$$\sqrt{\sigma} = 2\sqrt{\pi R} \frac{E_{\text{scattered},\phi} \text{ or } \theta}{|E_{\text{incident}}|}.$$  

(3)

As an example, Figure 7 shows a typical bi-static RCS (amplitude and phase) for a single ice-spheroid as a result of different incident wave polarization at $\theta = 0^\circ$ (backscattering) and different azimuth angles. Polarimetric radar signatures can be derived based on such data and can be used for further weather hazard characterizations. The reason that $\sqrt{\sigma}$ will be important for our future applications is when the PNA network analyzer and a rotary positioner is used, the amplitude and phase of $\sqrt{\sigma}$ can be directly measured based on vector-S-parameter concepts. Taking into account the phase of $\sqrt{\sigma}$ will allow further differentiation of different type of hydrometers or weather hazards.

### 5. CONCLUSION

A controlled lab-measurement approach is introduced to characterize dual-polarization scattering characteristics of hydrometeor hazards. An advanced network analyzer instrument is used as the centerpiece of the scatterometer measurement system. Preliminary results show that the lab-measurements agree well with theoretical calculations and the potential target discrimination capabilities. More realistic meteorological targets will be modeled for the experiments and calculation in future.

### REFERENCES


