CHARACTERIZATION OF VOLUME SCATTERING OF DRY SAND AT MILLIMETER-WAVE FREQUENCIES

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1. INTRODUCTION

Seismic tests are used in oil and gas-field explorations in desert and arid lands. Seismic tests are usually successful in sandy area where the sand layer thickness over the bedrock is low. Hence, the cost of these tests can be reduced significantly if the thickness of the sand layer above bedrock and hard clay is known a priori. One approach to map the sand layer thickness over a large area is to use a dual-frequency Interferometric Synthetic Aperture Radar (InSAR), whereby two InSAR systems, one operating at low frequency and the second operating at high frequency, are mounted on a single platform. The high-frequency InSAR, operating at millimeter-wave frequencies (MMW), is used to determine the height of the air/sand interface while the low-frequency (VHF) InSAR is used to determine the height of the sand/bedrock interface. Thickness of the sand layer is then the difference between the two heights. The premise for using a MMW InSAR is that the radar backscatter return at these frequencies originates from the air/sand interface or slightly beneath it. High extinction rate, due to absorption and scattering by the sand particles, limits the penetration depth of the MMW frequency signal to few centimeters of the sand layer. It is worth noting that scattering processes that contribute to the value of the backscattering coefficient, σ^o, of an isotropic, homogeneous, random medium (such as a dry sand layer) are in general: (1) surface scattering from the air/sand interface and (2) volume scattering from within the sand layer. It is observed that the air/sand interface of sand dunes can be characterized for the most part as "electrically smooth" surfaces, even at MMW frequencies, except for areas where prevailing wind produces small scale, one-dimensional, periodic surface, whose ripples are perpendicular to the wind direction. Surface height profiles, collected recently of the "roughest" patches of 4 different sights of sand dunes across the Kingdom of Saudi Arabia, have shown that the root-mean-square height, s, varied between 0.8mm and 3.6 mm. At 35 GHz, for example, these surfaces possess roughness parameters, ks (where $k=2\pi/\lambda$), that vary between 0.58 (electrically smooth) and 2.64 (electrically rough). Whereas surface scattering may be the dominant component of backscatter in many situations, only near-surface volume scattering is expected to consistently contribute to the backscatter return and constitutes the minimum level based on which the radar parameters must be designed. While significant amount of data and analysis is reported in the literature on volume scattering from snow-covered surfaces at millimeter-wave frequencies [1-2], not much data is available of dry sand.

2. MEASUREMENT AND MODELING OF RADAR RETURN FROM DRY SAND

In this paper, we will report on an ongoing measurement effort of a homogenous thick layer of dry sand with smooth air/sand interface. These measurements are performed indoors using two fully polarimetric instrumentation radars operating at 35 GHz and 95 GHz. The measurements are performed over a range of incidence angles between 30^o and 70^o, consistent with the range of elevation angles spanned by the proposed MMW InSAR system. To facilitate the creation of statistically independent spatial samples of sand, the sand is housed in a large box atop of a computer-controlled turntable. The antenna spots of the two instrumentation radars are off-centered with respect to the sandbox center and represent a small fraction of the sandbox area. This setup permits measurements of different sand volumes as the turntable is rotated. The measurements will be repeated for two different sand types with particle size distributions that are similar to those found in typical sand dunes.

The aforementioned measured data are valuable in their own right as they provide for the first time, controlled measurements of volume scattering contribution of homogeneous dry sand as a function of incidence angle, polarization, frequency, and particle size distribution. The outcome of these measurements will be compared against simulated backscatter response of dry sand, generated using dense medium radiative transfer theory (DMRT) [3-5]. Recently, volume scattering of dry sand was measured at a single incidence angle (55^o) using a vv-polarized instrumentation radar operating at 35-GHz. The measured return agreed closely with the vv-polarized response predicted by DMRT model [2] (the radiative transfer equations were solved numerically using the discrete-ordinate eigen-analysis technique [3]). The more extensive measurements reported in this paper will be compared against DMRT predictions, especially the cross-polarized response. Note that at 95 GHz, sand can no longer be assumed as a collection of Rayleigh particles, as some particles become “electrically large” particles at this frequency. Having Rayleigh particles is a fundamental assumption used in DMRT development. This paper will report on how well does the model agree with measurements at all frequencies.

A second, much simpler model, based on first-order solution of radiative transfer equation of semi-infinite medium (see Figure 1) will also be considered in this paper. In this model, the measured Mueller matrix of the random medium at a given incidence angle is used to calculate the phase matrix and extinction coefficient of the random medium [6]. This semi-empirical approach assumes that both the phase matrix and extinction of the random medium are independent of the incidence angle and dependent only on the medium’s electrical and physical properties. Once the phase matrix and extinction coefficient are known for a given medium and at a given frequency, it can be used to predict the response of the medium at all other angles. The model was successfully tested in the past at MMW frequencies on asphalt surfaces [6].

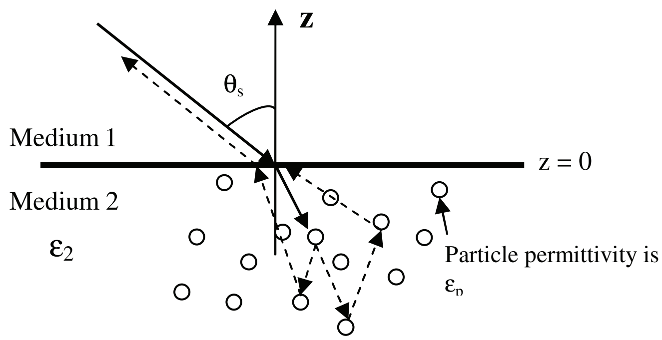

Figure 1: Depiction of scattering through dry sand medium occupying the lower half space.

3. CONCLUSIONS

This paper will report on new measurements of volume scattering contribution of dry sand at MMW frequencies. These first of a kind fully polarimetric data, are function of incidence angle, frequency, polarization, and particle size distribution. The data will also we examined against predictions made by solution of the DMRT model. Furthermore, the simpler, first order solution-based model [6], will be tested and used to create simple expressions that can be used by radar engineers to calculate the expected volume scattering response of dry sand at MMW frequencies.

4. REFERENCES

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