PRELIMINARY BROADBAND MEASUREMENTS OF DIELECTRIC PERMITTIVITY OF PLANETARY REGOLITH ANALOG MATERIALS USING A COAXIAL TRANSMISSION LINE. A. Boivin[1], C-A. Tsai[2], D. Hickson[3], R. Ghent[1,4], and M. Daly[3], [1]Department of Earth Sciences, University of Toronto, 22 Russel St., Toronto, ON, Canada, M5S 3B1, Email: alex.boivin@mail.utoronto.ca, [2]Department of Physics, University of Toronto, 60 St. George St., Toronto, ON, Canada, M5S 1A7, [3]Centre for Research in Earth and Space Science, York University, 4700 Keele St., Toronto, ON, Canada, M3J 1P3, [4]Planetary Science Institute, 1700 East Fort Lowell, Tucson, AZ, USA, 85719-2395.

Introduction and background: When considering radar observations of airless bodies containing regolith, the radar backscatter coefficient is dependent upon the complex dielectric permittivity of the regolith materials. In many current applications of imaging radar data, uncertainty in the dielectric permittivity precludes quantitative estimates of such important parameters as regolith thickness and depth to buried features (e.g., lava flows on the Aristarchus Plateau on the Moon and the flows that surround the Quetzalpetlatl Corona on Venus). For asteroids, radar is an important tool for detecting and characterizing regoliths. Many previous measurements of the real and/or complex parts of the dielectric permittivity have been made, particularly for the Moon (on both Apollo samples and regolith analogues) [e.g. 1, 2]. However, no studies to date have systematically explored the relationship between permittivity and the various mineralogical components such as presence of TiO_2 and FeO. For lunar materials, the presence of the mineral ilmenite ($FeTiO_3$), which contains equal portions FeO and TiO_2, is thought to be the dominant factor controlling the loss tangent (tanδ, the ratio of the imaginary and real components of the dielectric permittivity). Ilmenite, however, is not the only mineral to contain iron in the lunar soil and our understanding of the effect of iron on the loss tangent is insufficient. Beyond the Moon, little is known about the effects on permittivity of carbonaceous materials. This is particularly relevant for missions to asteroids, such as the OSIRIS-REx mission to (101955) Bennu, a carbonaceous asteroid whose regolith composition is largely unknown. Here we present preliminary broadband (300 kHz to 14 GHz) measurements on materials intended as planetary regolith analogs. Our ultimate goal is to establish a database of the effects of a wide range of mineralogical components on dielectric permittivity, in support of the OSIRIS-REx mission and ongoing Earth-based radar investigation of the Moon. In addition to facilitating quantitative interpretation of lunar radar data, our results will provide context into which samples returned by OSIRIS-REx will fit, and will therefore inform future remote exploration of asteroids.

As shown by [2, 3] and others, the loss tangent is particularly important when inverting for regolith thickness from radar observations. In the simplest case where scattering from roughness and rocks is ignored and where the signal frequency is known, radar attenuation (and therefore the backscatter coefficient) is dependent on the parameter $\varepsilon'' d/\mathrm{sqrt}(\varepsilon')$ where d is the thickness of the regolith, ε' is the real part of the complex permittivity (referred to as the dielectric constant), and ε'' is the complex part of the permittivity (referred to as the loss factor)[2]. Often when considering the dielectric loss of a material the loss tangent, tanδ, is reported. The loss tangent is the ratio of ε'' to ε'.

Objectives: Since the dielectric properties of powdered materials depend on several parameters (e.g. grain size and size distribution, density, porosity, mineralogy, temperature, frequency, moisture) we intend to systematically vary parameters with a focus on mineralogy. We begin by varying TiO_2 content in a base powder of alumina oxide under ambient conditions. Future plans include measurements at different temperatures and under vacuum conditions. We will begin to investigate mineralogy by varying FeO content as well as a combination of both TiO_2 and FeO. These results will be compared with the mineral ilmenite which will be crushed and sieved into a powder of known grain size. Carbonaceous materials which are relevant to carbonaceous asteroids such as Bennu are also planed to be measured with this technique.

Method: We measure both parts of the dielectric permittivity using an Agilent Technologies E5071C ENA Series network analyzer capable of sweeping through frequencies from 300 kHz to 14 GHz. The network analyzer is connected to a coaxial transmission line (either 7 mm diameter and 10 cm length or 14 mm diameter and 15 cm length) which is filled with a powdered material according to the methodology established in [4]. Signals generated from the network analyzer are reflected from either end of the sample, and transmitted in both directions through the sample; the resulting reflection and transmission coefficients result in S-parameters, from which we compute the complex permittivity (dielectric constant and loss factor). We use the non-iterative method established by

[5] and demonstrated for this method in [4]. During a measurement the airline is kept upright to avoid powder displacement. The network analyzer is calibrated using known calibration standards prior to each measurement.

Data: One example permittivity measurement is shown for a powdered sample in Figures 1 and 2. Both the dielectric constant (ε') and the loss tangent are plotted for frequencies between 500 kHz and 14 GHz. Frequencies bellow 500 kHz were omitted due to large error in that range. The sample consists of 76 µm alumina oxide powder with the addition of ~0.5 weight% TiO_2 powder. The sample was measured in the 7 mm airline which has a volume of ~12.44 cm^3. The density of the powder in the airline was 0.41 g/cm^3. Note that dielectric properties of materials also depend on density, porosity and grain shape.

As can be seen in Figure 1 the dielectric constant for the sample is stable with frequency while the loss tangent (Figure 2) shows a slight frequency dependence. Relative error in the loss tangent measurements is also much larger than for the dielectric constant with the calculated loss tangent sometimes dipping below 0. It is expected that refinement of the experimental method, particularly better control on packing and grain size, will yield more precise loss tangent results.

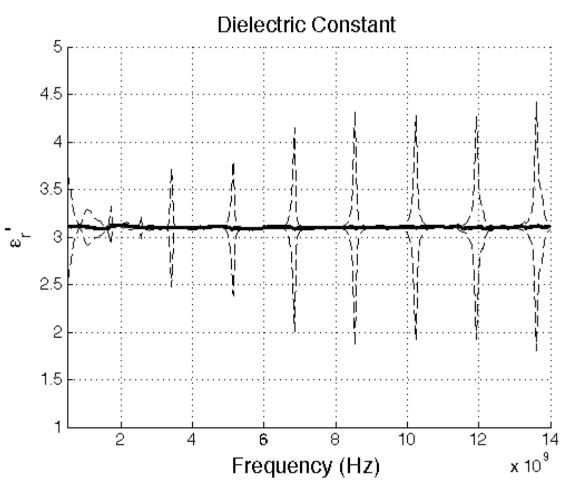

Figure 1: Plot of dielectric constant measured between 500 kHz and 14 GHz for one sample of 76 µm alumina oxide powder + 0.5 weight% TiO_2 powder with a density of 0.41 g/cm^3 in the 7 mm airline. Dashed contours correspond the the uncertainty in the measurement according to [4-6].

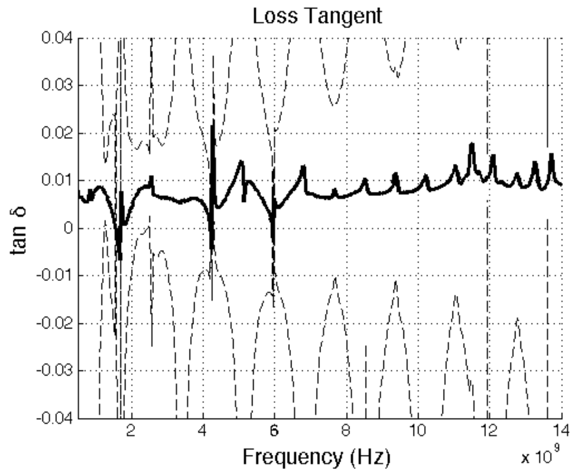

Figure 2: Plot of loss tangent measured between 500 kHz and 14 GHz for one sample of 76 µm alumina oxide powder + 0.5 weight% TiO_2 powder with a density of 0.41 g/cm^3 in the 7 mm airline. Dashed contours correspond the the uncertainty in the measurement according to [4-6].

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