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

Introduction: Radar has long been used as a tool for remote sensing of planetary bodies. High quality Earth based imaging radar is useful for investigating the subsurface and for producing 3D models of near-Earth asteroids. Radar systems have been in orbit of the Moon, Mars, Venus, and Mercury. Despite an abundance of radar data, lack of information on the dielectric properties of the surface and near-subsurface materials of these bodies preclude detailed quantitative analysis of radar data. This includes determining the precise depth of radar-detected subsurface features (e.g., lava flows on the Aristarchus Plateau on the Moon and the flows that surround the Quetzalpetlatl Corona on Venus) as well as refining estimates of abundance of subsurface conductive materials such as the mineral ilmenite, which are known to attenuate radar signals on the Moon. Although laboratory measurements have been made in the past in order to quantify dielectric properties of Lunar and Martian materials, these measurements provide a limited view of the parameter space of influence on dielectric properties. This precludes detailed modelling efforts.

Here we present preliminary broadband (500 kHz to 14 GHz) measurements on materials intended as planetary regolith analogs. As planetary regoliths are devoid of moisture and are in vacuum conditions, we make our measurements in vacuum. 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. We begin by measuring 2-component mixtures of well-characterized materials relevant to the Lunar regolith with the goal of comparing our results with past measurements before progressing to materials more relevant to the OSIRIS-Rex mission. This abstract presents one such example measurement. Future plans include measurements at different temperatures as well as other mineralogical mixtures.

Background: Although new data of all kinds are being acquired from all over the solar system, relatively little is known about the composition of asteroids. They make up an enormous and highly varied population of bodies in our solar system. Understanding the composition and physical properties of these bodies is key to understanding the origin and evolution of the solar system. Asteroids (as well as comets) are the closest available relatives to the building blocks that formed the planets of our solar system. Despite the numerous events that have shaped their current physical and orbital properties, they contain, relative to the planets, a pristine record of the initial conditions of our solar system nebula [1]. Although samples of regolith have been retuned from the Moon and extensively studied [e.g., 2, 3] very little asteroid surface material has been returned to Earth. Thus the Moon serves as an analogue to asteroids [4, 5].

The dielectric properties of materials are described by a complex value (called permittivity or dielectric constant, $\varepsilon = \varepsilon' + i\varepsilon''$) that depends on frequency, bulk density, porosity, moisture, and mineralogy. Our understanding of these contributions is minimal and thus investigations of bulk composition of planetary bodies are hampered. 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. 2, 6]. 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 ($\tan \delta$, the ratio of the imaginary and real components of the dielectric permittivity). 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. Spectroscopically, CI and CM group meteorites most closely resemble OSIRIS-REx target Bennu, with CIs being the closest [5].

Objectives: Since the complex 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 powdered ilmenite content in a well-characterized base powdered material under vacuum. The goal is to systematically determine the influence of weight percent ilmenite on the permittivity of the Lunar regolith. Ilmenite was chosen as a starting material to measure due to its high loss tangent, which strongly attenuates radar signals traveling through the Lunar surface. Once the accuracy and validity of the methodology is verified, more complex mixtures and asteroid relevant materials will be measured.

Method: We measure both the real and imaginary 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 [7]. Signals generated from the network analyzer are reflected from either end of the sample, and transmitted in both directions through the sample; the reflection and transmission of the signal results in scattering parameters, from which we compute the complex permittivity. We use the non-iterative method established by [8] and demonstrated for powders in [7]. The network analyzer is calibrated using known calibration standards prior to each measurement.

Data: Figures 1 and 2 show preliminary results of one example measurement under vacuum of ilmenite mixed with alumina. Alumina was used as a base material since is has been well characterized and exhibits weak to no frequency dependence [7]. Vacuum was maintained at 0.48 Torr (0.064 kPa). Both the dielectric constant (ε') and the loss tangent ($\tan \delta$) 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 aluminum oxide powder with the addition of ~10 weight% ilmenite powder. The sample was measured in the 7 mm airline, which has a volume of 3.11 cm^3. The bulk density of the powder in the airline was 2.11 g/cm^3. Bulk density was measured by weighing the transmission line before and after being filled with the sample. Note that dielectric properties of materials also depend on density, porosity and grain shape.

Although the measurement is noisy, the real part decreases slightly with frequency from approximately 4.2 to 4.1. The loss tangent exhibits the opposite trend and increases from ~0.01 to ~0.02 with increasing frequency. Both values are consistent with expected results from the Lunar regolith given bulk density and w% ilmenite [2]. These materials exhibit weak frequency dependence in this range. Further measurements in the 14 mm transmission line with improved calibration are expected to reduce noise in the measurements.

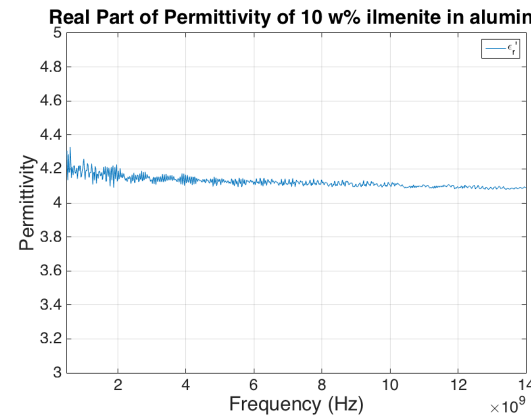

Figure 1: Real part of the complex permittivity (dielectric constant) of 10 weight% ilmenite powder in aluminum oxide powder.

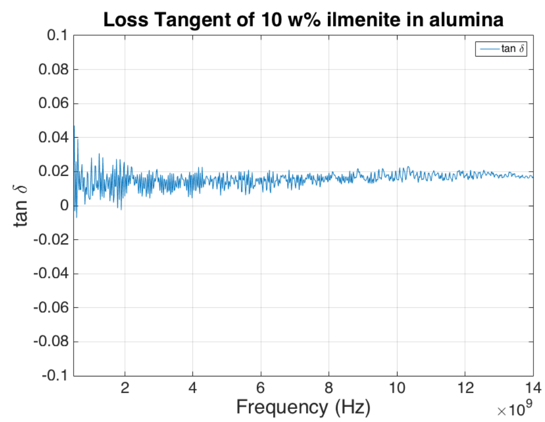

Figure 2: Loss tangent of 10 weight% ilmenite powder in aluminum oxide powder.

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