Permittivity Sensors for Planetary Exploration. C. Gscheidle[1] and P. Reiss[1], [1]Technical University of Munich (Lise-Meitner-Str. 9, 85521 Ottobrunn, Germany, c.gscheidle@tum.de).

Introduction: Precise knowledge of the distribution, abundance and physical state of lunar volatiles is crucial for planning future missions to the Moon. The data from numerous remote sensing missions around the Moon has provided strong evidence for large reserves of water equivalent hydrogen, however ground truth data for verification and model correlation is still lacking especially for the lunar poles. Although upcoming exploration missions, such as NASA's VIPER and ESA's PROSPECT, will hopefully improve the ground truth data availability, broader coverage and finer spatial resolution is still necessary.

Measuring the regolith's electrical permittivity is a relatively simple and scientifically valuable technique to quickly determine the state and abundance of water ice. Multiples missions to the Moon and other celestial bodies have used or intend to use permittivity sensors [1,2,3,4].

Electrical Permittivity of Regolith: The electrical permittivity (or dielectric constant) is a measure of the electric polarizability of a dielectric and thus describes its ability to store energy in an electric field. Any mixture of materials between two electrodes and their respective relative permittivity influences the system's electric capacitance. In the context of planetary exploration, this phenomenon can be exploited as the relative (static) permittivity of vacuum (=1), dry regolith (~5-8), and water (liquid and ice, ~80-100) differ significantly in both magnitude and behavior in the frequency domain over temperature [5]. Measuring the capacitance of a calibrated system thus allows for deduction of the material's permittivity and subsequently its water content.

Permittivity sensors exhibit several advantages for application on spacecraft: They are lightweight, require very low power and can cope with harsh environments while providing scientifically valuable data. The measurement principle is based on applying a square wave excitation potential with given switching frequency and measuring the transient charging process. This characteristic time series yields frequency domain information when being Fourier-transformed.

Besides the (relative) electrical permittivity, such sensors can also provide information on the material's electric conductivity and magnetic properties over frequency.

Developments: TUM is involved in multiple permittivity sensor development activities, some of which are shown in Figure 1:

- The Lunar Volatiles Scout (LVS) is an instrumented drill designed for exploring the lunar poles by characterizing thermally extracted volatiles with an integrated mass spectrometer and pressure sensors [6]. Its drill shell geometry forms a cylindrical capacitive system with the central heating element, which can be employed to perform permittivity measurements to extend the LVS capabilities. This system can be integrated into a (small) rover to explore the spatial distribution of volatiles across the surface and to a depth of up to 20 cm [7].
- The instrument package PROSPECT, developed by ESA, includes a permittivity sensor integrated into its drill to measure the subsurface regolith properties and detect water ice, as well as determine the geometry of the borehole [1]. The measurements from this instrument will provide information about the distribution of water over depth and constrain the potential loss of volatile water during sampling.
- Drawing from the above involvements, we are currently investigating different forms of patch electrodes for permittivity sensors. These flat and light electrodes could be attached to otherwise unused surfaces of exploration systems, such as wheels of rovers or lander foot pads. Valuable data on the subsurface can be acquired herby using only minimal resources.

Alongside the development of electrodes, the necessary electronics is also developed, intended to function on minimal resources from the host system (one switchable output, one analog input channel, small currents).

Experimental Results: All sensors mentioned in the previous section have been demonstrated to work as expected via simulation and experimental investigation. For this, we used regolith simulants mixed with different amounts of water over a broad range of temperatures as well as calibration objects with known permittivity. The results have shown a statistically significant correlation with both theory and results of coupled multi-physics simulations. As an example, Figure 2 shows results from insertion depth experiments with the LVS with correlation coefficient above 0.95 and a r^2 above 0.95.

Based on the simulation results, we plan to analyze and subsequently optimize the system with respect to measurement range, parasitic capacitances, sensitivity,

Figure 1: Pictures and renderings of permittivity electrodes. Left: Lunar Volatiles Scout electrodes: drill shell and heater. Center: PROSPECT permittivity sensor in drill rod. Right: Patch electrode prototype.

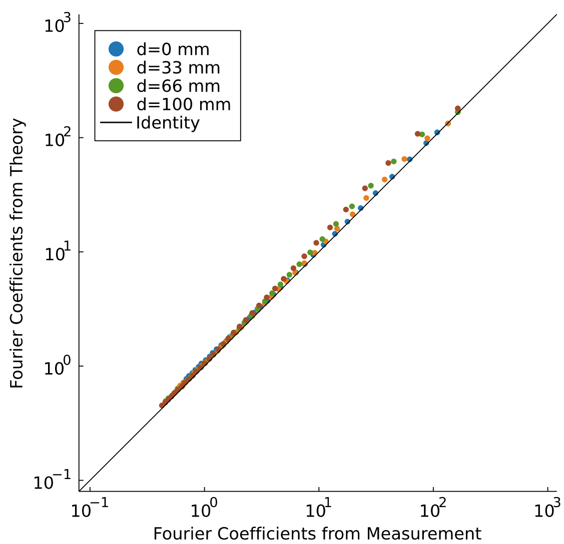

Figure 2: Correlation between simulations and experiments from insertion depth study.

noise, geometry, and manufacturability. Owing to their simple design, these permittivity sensors can be adapted to fit a variety of mission architectures, accommodations, and configurations.

Conclusion: Prospecting for water on the surface of the Moon and volatiles on other celestial bodies greatly benefits from the availability of rapid in-situ surveying techniques. Especially for mobile platforms, compact and simple instruments are advantageous. The proposed permittivity sensor technology offers scientific instrumentation for the characterization of volatile water in a small and simple package that can be integrated in existing designs with little additional effort.

Experiments under representative conditions and correlation with coupled multi-physics simulation confirm the feasibility of this technique in the small package and multiple geometries. Further experiments will focus on determining mixing laws and model correlation for further design verification.

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