A Rover Permittivity Sensor for In-Situ Lunar Water Ice Detection

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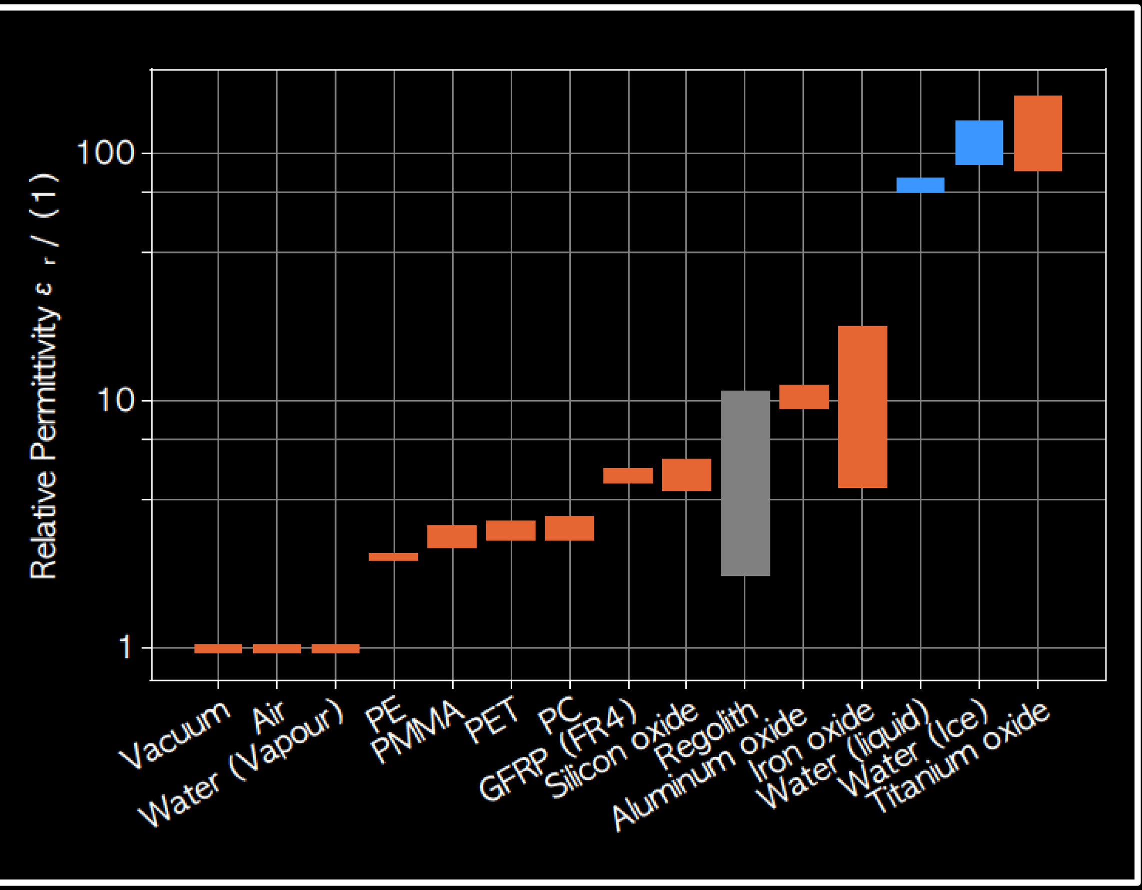
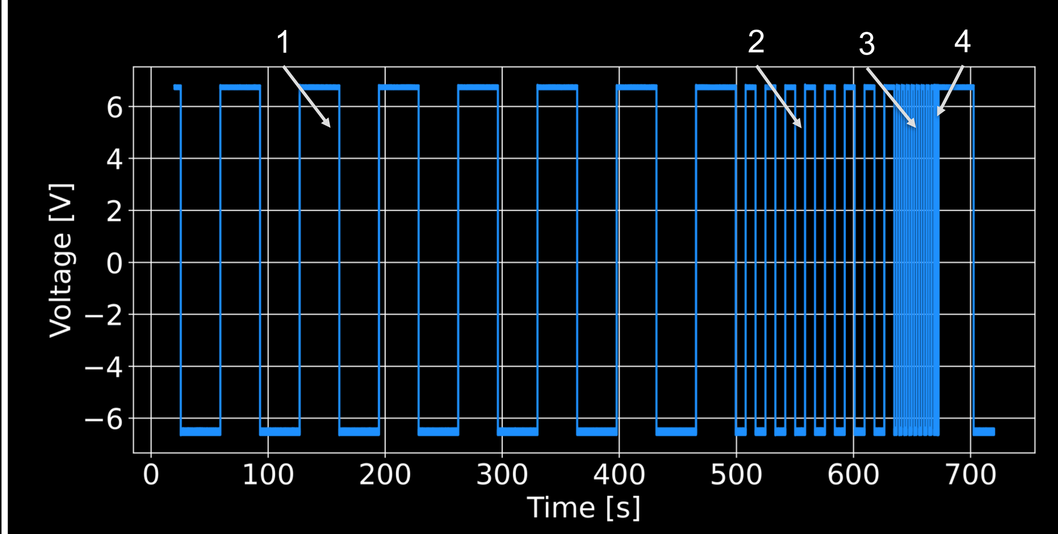
Project Overview

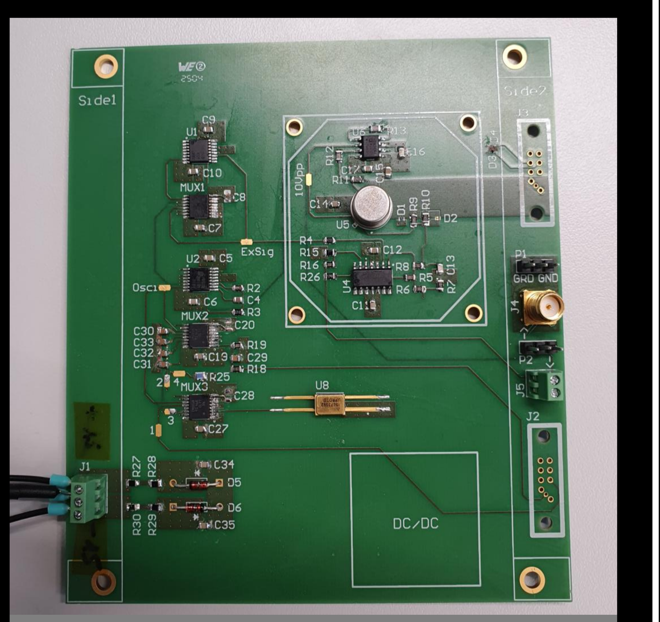
- Instrument: **Permittivity sensor** as an ESA payload for a **lunar rover mission** [1]; cooperation with the Mohammed Bin Rashid Space Centre (MBRSC, UAE)
- Estimated Launch Date: **2028**
- Targeted Landing Site: Lunar **polar region**
- Aim: **Non-intrusive in-situ characterization** of the regolith in the shallow subsurface along the rover track
- Method: Lunar soil acts as a dielectric between the two electrodes of a capacitor. From the measurement of the soil's **bulk electric permittivity**, the **soil porosity** and its **chemical composition** can be determined. The method takes advantage of the significant difference between the relative permittivities of **vacuum** (ε_r = 1), **regolith** (ε_r ~ 5 [2]), and **water ice** (ε_r ~ 80 [3]). The strong temperature dependence of the water relaxation frequency requires an additional **regolith temperature measurement**.
- Heritage: The design is based on the permittivity sensor in the PROSPECT instrument package [4]. The permittivity sensor concept was already demonstrated on other missions such as Cassini-Huygens [5] and Rosetta [6].



1. Electronics Unit

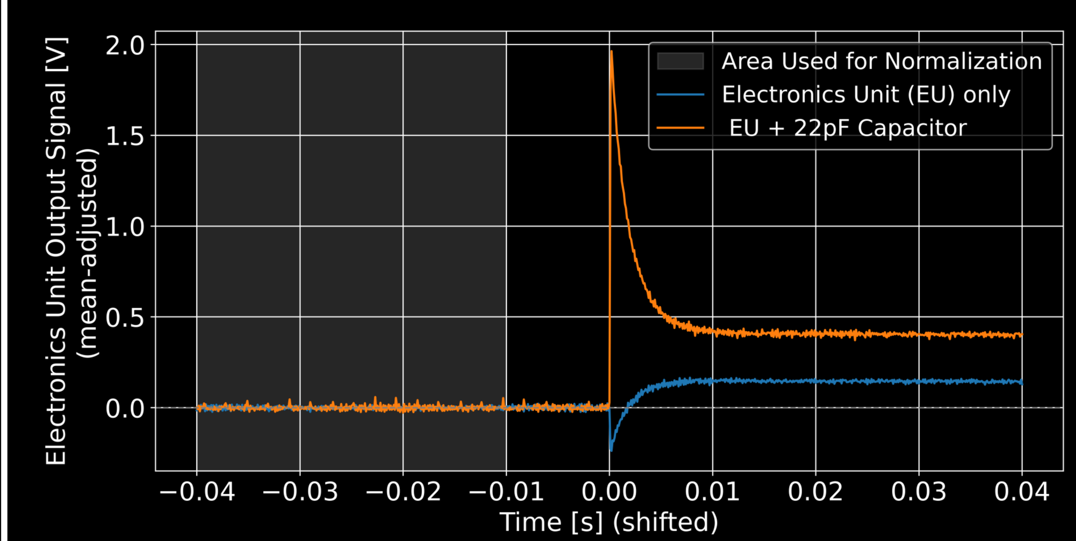
- Four square-wave excitation frequencies to account for the temperature-dependent water ice relaxation frequency down to cryogenic temperatures (down to 40 K is seen in some lunar polar craters [7]).





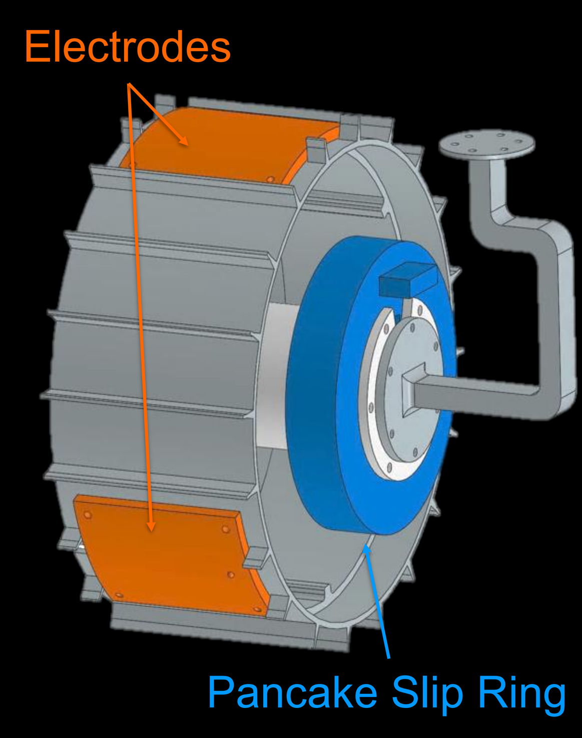
Prototype of the Electronics Unit

- Excitation frequencies are applied in sequence via a current measurement resistor to the electrodes.
- The permittivity of the bulk material can be determined from the current measured across the resistor.
- The expected measured current is low → electrical design is optimized for low parasitic capacitance achieved by shielding the sensitive measurement signal.

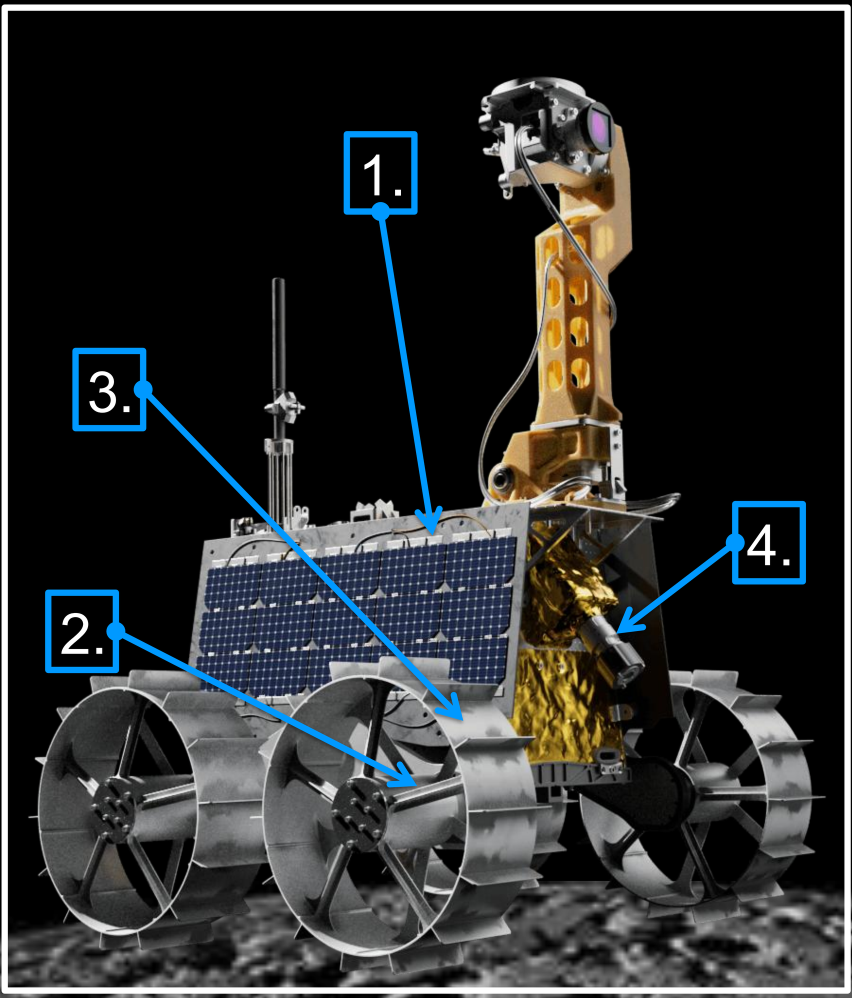


2. Pancake Slip Ring

- Shielded connection between the electrodes on the wheel and the electronics inside the rover body.
- Mechanical and electrical design minimize the parasitic capacitance.
- Must not affect the reliability of the wheel by increased friction.
- Dust-tolerant design approach - to be verified.

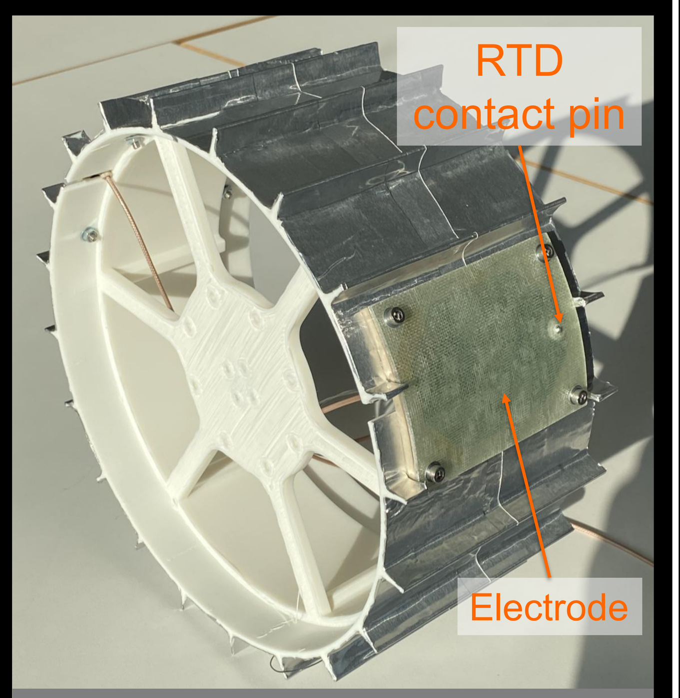


Prototype Slip Ring PCBs in their Mechanical Housing



3. Wheel-Mounted Electrodes

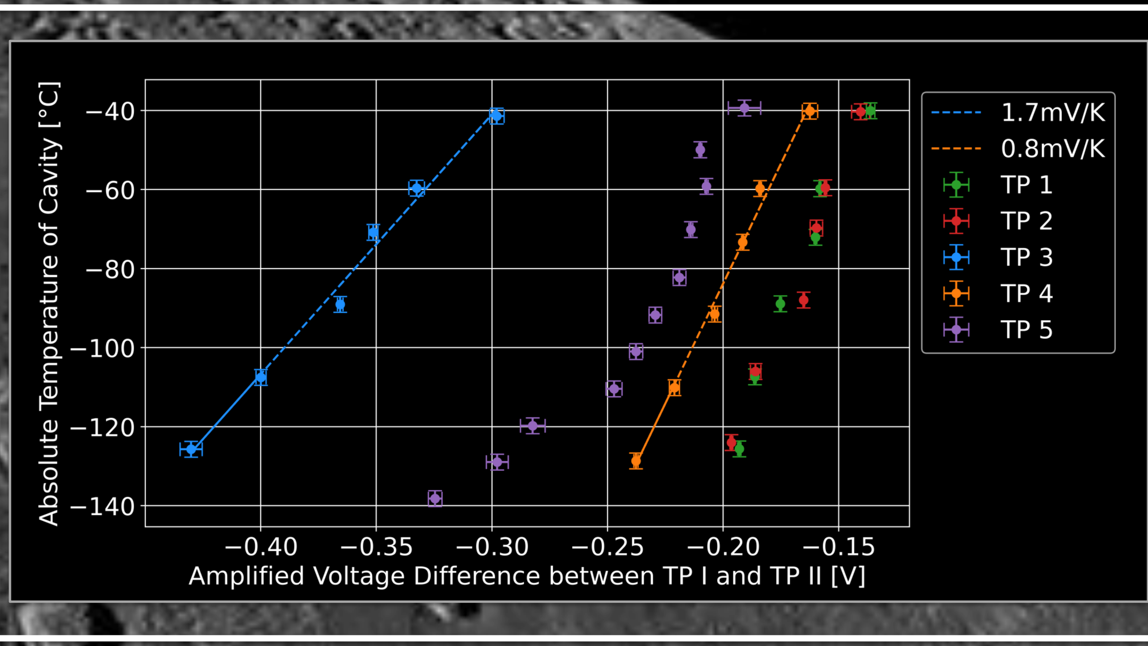
- In contact with undisturbed lunar regolith every wheel revolution.
- Investigable depth depends on electrode size. → Electrodes of different sizes are foreseen.
- Isolating cap protects against ESD events and mechanical damage.
- Integrated RTD for contextual temperature data.

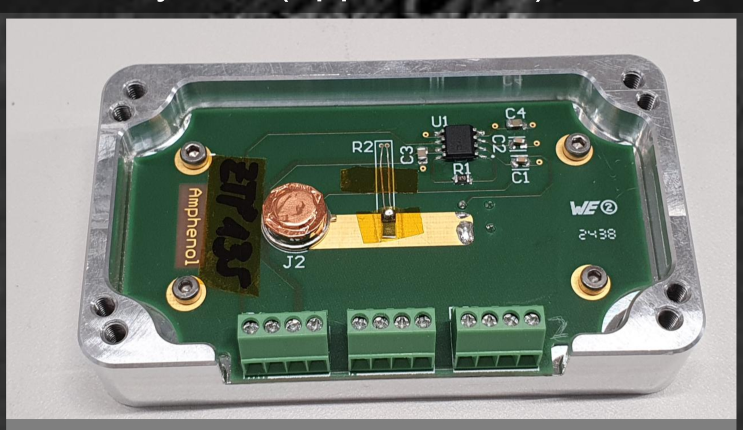


Electrode with Integrated RTD on Rover Wheel Mock-up

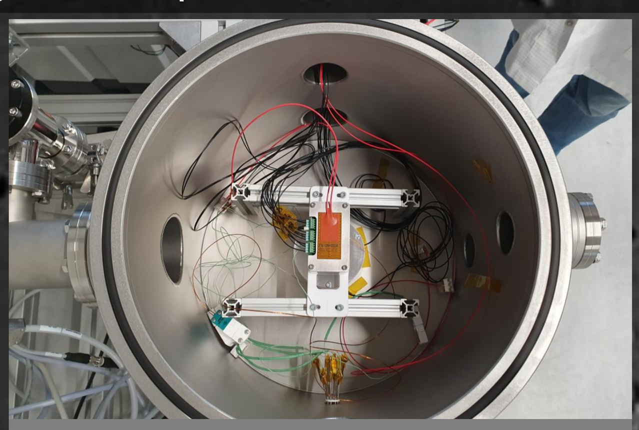
4. Infrared Temperature Measurement Unit

- Collects contextual temperature information.
- Its thermopile sensor sees the undisturbed lunar regolith a few decimeters ahead of the rover. Targeted performance is an accuracy of ±5 K or better within a surface temperature range of 373 K to 100 K.
- Thermopile sensors are commonly used for high-temperature measurements.
- We tested the performance of various candidate sensors at cryogenic temperatures in a feasibility study.
- Target temperature down to -140 °C (sensor constantly at 20 °C) in the feasibility study.
- Sensitivity and (approximate) linearity at cryogenic temperatures have been successfully demonstrated.





Prototype of the IR Temperature Measurement Unit



Thermopile Cryogenic Temperature Test Setup

Acknowledgement

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References

[1] Trautner, R. et al. (2024) European Lunar Symposium [2] Chung, D. H. et al. (1972) Proceedings of the Lunar Science Conference, vol. 3, p. 3161. Vol. 3. [3] Uematsu, M. and Franck, E. U. (1980) Journal of Physical and Chemical Reference Data 9.4 1291-1306. [4] Trautner, R. et al. (2021) Measurement Science and Technology 32.12 125117. [5] Fulchignoni, M. et al. (2002) Space Sci. Rev. 104, 395–431. [6] Seidensticker, K. J. et al. (2007) Space Sci. Rev. 128, 301–337. [7] Nurge, Mark A. (2012) *Planetary and Space Science* 65.1 76-82.
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Rover Image Credit: MBRSC (Rashid-1/2 rover. Rashid-3 rover will look different)