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# Development of a Multi-Needle Method for Measuring Thermal and Electrical Properties of Soils for Application on Planetary Lander Missions

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## Abstract

We report on the development of a physical properties probe with the potential to be applied both in space research as a payload for planetary lander missions and for terrestrial field research in remote areas. The probe will measure in situ the thermal and electrical properties of the soil. The concept behind the probe combines classical methods for measuring heat conductivity and electrical permittivity and conductivity.

## 1. Introduction

Basically the design consists of an array of four vertically oriented steel needles, equipped with high precision temperature sensors and heaters for the thermal conductivity measurements [1], which at the same time can act as electrodes for the electrical permittivity measurements. Due to this multiple needles configuration not only thermal conductivity, but also volumetric heat capacity can be derived from the measured data.

The whole design is intended to be used primarily in regolith type materials, which typically is composed of irregularly shaped grains in a low gas pressure environment (Mars) or even at high vacuum (Moon).

## 2. Measurement Principles

### 2.1. Thermal Sensors

In order to test the ability of the method to measure soil thermal conductivities in the extremely low conductivity range characteristic of planetary regolith first measurements were performed with an instrument mock-up assembled from existing single needle thermal conductivity sensors. In parallel model calculations assuming such a four needle configuration have been made using a finite element package.

For the description of the temperature around the heated needle and its two neighbours an analytic dual probe approach for infinite cylinders is well applicable. The results of numerical simulations (finite element method-FEM) for a 4-needle probe with one needle heated are illustrated in Figure 1. These results are compared with an analytic approach ([2] for a horizontal cross-section around needle 3 in Figure 2. The isothermal lines are bent around the non-heated probes because of their high thermal conductivities which cause a thermal short-circuiting effect.

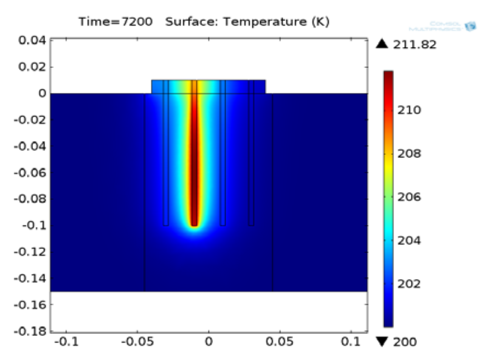


Figure 1: Result of a numerical FE-simulation showing the temperature field in a granular soil with a thermal conductivity of 0.05 W/m/K with an inserted four needle sensor. The graphic shows the

temperature distribution in the sample in response to heating Needle 2 with a constant power of 0.3 W for 2 hours.

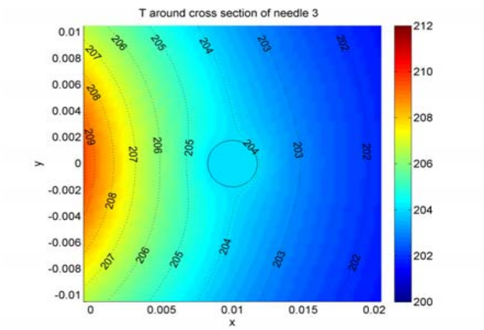


Figure 2: Comparison of the temperature fields around needle 3 after an adjacent needle for two hours. The contour lines are calculated by a semi-analytic method and give good coincidence with the FEM solution (in color code).

## 2.2. Electrical Sensors

The electrical properties measurements are based on a classical geo-electrical approach using four electrodes [3]. These electrodes are spaced like a Wenner array Type A as shown Figure 3.

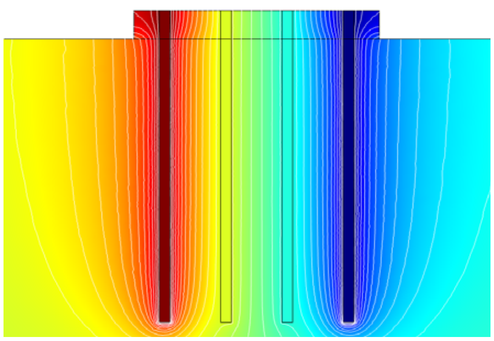

Figure 3: A typical distribution of the electrical potential for a four needle configuration.

Since the needles used for the thermal measurements are electrical conducting no extra electrodes need to be introduced.For operations the outer electrodes are used to transmit an alternating current into the material and the two inner electrodes sense the differential voltage which is attenuated and phase shifted with respect to the transmitted signal. The transmitted signal can be varied in frequency and amplitude to accommodate different material properties and a spectral resolution of the electrical properties.

## 3. Summary and Conclusions

For both methods the usage of multiple sensor needles enables a more accurate measurement of thermal and electrical properties by themselves by e.g. eliminating electrode surface effects. Some properties like e.g. the volumetric heat capacity can possibly not measured by one single needle alone.

An additional benefit comes from the combination of both measurements into one instrument which allows monitoring e.g. the simultaneous change of the electrical properties due to temperature changes of the environment. Any advanced modeling of soil textural properties will also benefit from a combined measurement of both thermal and electrical properties and invaluable soil parameters like the density can at least be narrowed down to a larger extent.

## References

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