A MINIATURE SOIL MOISTURE SENSOR TO SEARCH FOR MARTIAN BRINES.

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Introduction: Liquid brines are of special interest to NASA's Mars Exploration Program because they are essential to understand the potential habitability of the planet. Here we discuss a miniature microwave soil moisture sensor capable of probing the shallow subsurface of Mars to measure the abundance and distribution of brines, without the need for a drill.

This abstract is submitted in response to Challenge Area 1 of the Concepts and Approaches for Mars Exploration: *Instrumentation and Investigation Approaches*— In particular, it addresses item 1 of the near term goals, the interrogation of the shallow subsurface of Mars from the surface (e.g., sounding, drilling, excavating, penetrators, or other approaches).

Background: The Phoenix Mars Lander discovered perchlorate salts which can form liquid solutions at Mars' current environmental conditions [1] and found physical and thermodynamical evidence for liquid brines at its landing site [2, 3]. Then, Zorzano *et al.* showed experimental evidence that liquid brines are likely to form at the Phoenix landing site [4]. Renno *et al.* [2] hypothesized that the thermodynamics of freeze-thaw cycles causes the formation of brine pockets in saline soils such as that on the Phoenix landing site. The process is analogous to desalination by natural freezing, a process by which ice precipitates and separates from a saline solution when its temperature falls below its freezing point value as sketched in Figure 1. When the soil temperature oscillates around the eutectic temperature T_{Eut}, freezing increases the concentration of the solution until the eutectic concentration is reached [5]. Water molecules from the precipitated ice become available and diffuse into deliquescent salts in the soil. This process drives the salt concentration in the solution towards the eutectic value.

If this hypothesis is correct, then liquid brines could form almost anywhere where ground ice is present near the surface of Mars [2]. If liquid brine is present on Mars, it has important implications for weathering, glaciology, geochemistry, and habitability.

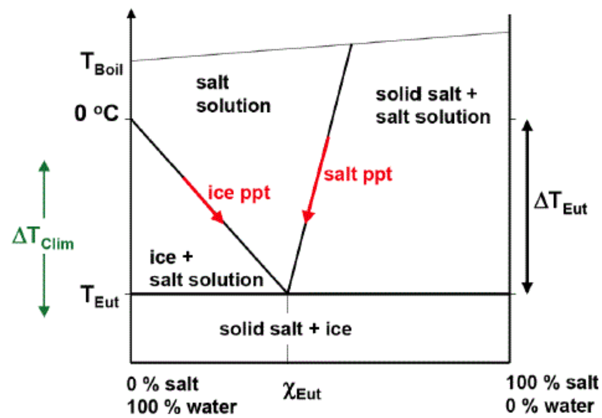

Figure 1: Sketch of the phase diagram of the aqueous solution of a generic salt.

Instrument Description: We have designed, fabricated and characterized a brassboard version of a flight-qualifiable soil moisture sensor to search for brines in the martian soil. This sensor is based on microwave resonators developed at the University of Michigan [6, 7]. Studies have shown the dependency of the electrical permittivity and conductivity of sand and soil within a frequency range of 0.6 to 10 GHz on the moisture of the sample. The sensor will simultaneously measure the soil dielectric constant and loss factor (the complex permittivity) by measuring a shift in its resonant frequency and the broadening of its resonance curve (see Figure 2) when the sensor is placed in contact with the soil, but not necessarily inserted in it. While most of the past experiments have been conducted at one single frequency, the revised version of this sensor will measure the permittivity of the soil at three different frequencies within the range mentioned above. This will enable the detection of brines in different depths. A schematic of the instrument is shown in Figure 3.

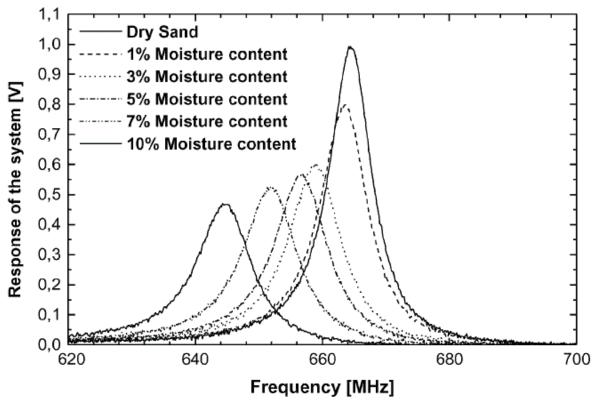

Figure 2: Measured transmission response for resonator as a function of the moisture content of sand placed under the substrate, from [Fratticcioli et al, 2004].

We envision this sensor being used to detect changes in the hydration state of the brines forced by diurnal or longer cycles. Moreover, we envision the sensor being deployed with other instruments capable of characterizing the physical and chemical properties of the soils, because our preliminary results suggest that the knowledge of the chemical and physical properties of the soil would provide strong constraints on its moisture.

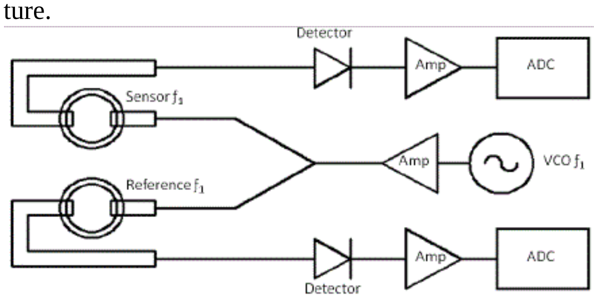

Figure 3: Schematic of Mars brine sensor instrument.

Currently, we are evaluating the performance of several versions of small resonators during measurements at Mars conditions. The purpose of our evaluation is to determine the sensitivity of different versions of the sensor to variations in the physical properties of the soil and its moisture and salt content. Several versions of the sensor, including a microstrip ring resonator, a ½-wavelength slot resonator, and a ¼-wavelength stub resonator have been studied [7]. However, these studies need to be refined for the planetary applications and so much work is being done to raise the Technology Readiness Level of these sensors to TRL 5. The basic components have been integrated with reasonably realistic supporting elements and the brassboard instrument tests in a simulated Mars environment are ongoing.

Instrument Calibration: The University of Michigan Mars environmental chamber has been fabricated to simulate the temperature, pressure, and humidity conditions of Mars Phoenix landing site [8]. This chamber allows us to study the formation of brine layers in martian soil simulants and characterize and calibrate the microwave brine sensor. An initial calibration of the resonance frequency, which defines the soil permittivity, and quality factor, which defines the amount of aqueous saline solutions in the soil has already been performed.

Implementation Plan: The main goals of the current project are to develop and test a brassboard version of a flight-qualifiable sensor capable of:

1. Measuring soil moisture content and bulk density in the top 0.1 m of the Martian soil, or even deeper if a drill is available.
2. Using variations of the frequency and quality factor of resonators to constrain the permittivity properties of the soil.
3. Detecting the presence of brine layers and pockets a few millimeters thick such as those suggested by the Phoenix measurements.

References: [1] Hecht, M. H. et al. (2009) *Science*, **325**, 5936. [2] Renno, N. O. et al. (2009) *J. Geophys. Res.*, **114**, E00E03. [3] Smith, P. H. et al. (2009) *Science*, **325**, 5936. [4] Zorzano, M.-P. et al. (2009) *Geophys. Res. Letters*, **36**, L20201. [5] Wankat P. C. (1973) *Desalination*, **13**, 147–157. [6] Kendra J. R. et al. (1994) *IEEE Trans. Geos. Rem. Sensing*, **32**, 1152–1159. [7] Sarabandi K. and Li E. S. (1997) *IEEE Trans. Geos. Rem. Sensing*, **35**, 1223-1231. [8] Elliott, H. M. *et al.* (2012), *LPSC Abstracts*, **43**, 2117.